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COMPOSITION, DIGESTIBILITY AND ENERGY VALUES OF SOME HUMAN FOODS

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This bulletin presents the average chemical composition of a number of human foods of which Texas analyses were made, human digestion experiments on cabbage, collards, oat meal and string beans, the average digestibility of human foods as compiled from the literature, factors for calculating the metabolizable energy and productive energy of human foods, a comparison of the fuel values as usually calculated with the metabolizable energy, and the productive energy for the human diet as compared with allowances recommended of metabolizable energy.

The calories of fuel values as ordinarily calculated are too low for many foods of animal origin and too high for foods of vegetable origin on account of the assumption that all human foods have the same digestibility. The metabolizable energy values as here calculated give more nearly correct results.

The productive energy is measured by the energy stored as protein and fat by growing chickens from that part of the ration fed in excess of maintenance. The productive energy values of human foods are not always in the same proportion to the metabolizable energy. The relative energy values of human foods are probably given more nearly correctly by the productive energy values than by the metabolizable energy values.

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This publication deals chiefly with the energy values of human foods. Students of animal nutrition have for a long time recognized that one pound of the digestible nutrients of one feed is not necessarily equal in energy value to one pound of the digestible nutrients of some other feed; for example, one pound of the digestible nutrients of straw has a much lower energy value to ruminants than one pound of the digestible nutrients of corn. Books of Kellner (41), Armsby (1), Fraps (18), Morrison (49), Brody (9) and others have discussed this subject, and scientific papers by Armsby, Fraps, Forbes, H. H. Mitchell, Brody and others have dealt with various aspects of the subject of the net energy or productive energy values of feeding stuffs.

The net energy concept has received little application to human foods and nutrition. A Bankhead-Jones project on the productive values of human foods at the Texas Agricultural Experiment Station was approved November 1, 1935. The object was to study the productive values of human food. The plan proposed to use animals chiefly, although some human experiments might be made. The animals were to be grown on the foods to be tested and the productive values of the foods estimated from the gains of protein and fat. Digestion experiments were to be made. The effect of various factors on the productive values were to be estimated. Productive values were to be calculated from the data secured as well as from any other data that could be available.

A number of publications have been made on various phases of this project, and on a similar project relating to animal feeds (22, 28, 29, 30, 32). This bulletin deals with analyses of some human foods, a few digestion experiments, average digestion coefficients, fuel values and metabolizable energy values and factors for calculating them, factors for calculating productive energy, the productive energy of some human foods, and other data relative to the subject especially as applied to human nutrition.

Constituents of Human Foods

In the ordinary analysis of animal feeds, determinations are made of protein, ether extract (fat), water, ash and crude fiber. The sum of these is subtracted from 100 and the difference is termed nitrogen-free extract. In the similar analysis of human foods, the determination of crude fiber is often omitted, and the sum of the protein, ether extract, water and ash subtracted from 100 gives what is termed carbohydrates (12, 54). The term carbohydrates as thus used is the sum of the nitrogen-free extract and crude fiber, if crude fiber is present. The term carbohydrate as used by chemists means compounds containing carbon combined with hydrogen and oxygen in the proportions to form water, and as used above for human foods, is incorrect, because although true carbohydrates are present, organic acids, lignins and other non-carbohydrates are also contained in many human foods. Crude fiber is not present at all, or in very small percentages in many human foods, such as meat, milk, eggs, white bread, white flour and potatoes. Crude fiber is, however, present in appreciable proportions in vegetables, fruits and nuts.

The average percentage of crude fiber in the so-called carbohydrates in some human foods is given in Table 1. Vegetable foods may also contain appreciable percentages of uronic acid, as is shown in Table 2

Table 1. Percentage of crude fiber in percentage of so-called carbohydrates

	Crude Fiber Percent		Crude Fiber Percent
Nuts			
Almond	13	Pumpkin	19
Brazil nuts	19	Turnip roots	15
Chestnut	3	Fruits	
Coconut	21	Apples	7
Peanut	11	Prunes	2
Pecans	17	Dates	3
Walnut, English	13	Figs	9
Vegetables		Grapes	4
Potato, white	2	Olive	30
Potato, sweet	3	Pears	8
Mustard greens	20	Persimmon	10
Spinach	19	Cereals	
Chard leaves & stalks	20	Barley, pearled	1
Turnip greens	23	Corn	3
Broccoli	24	Oat meal	2
Cabbage	19	Rye flour	3
Celery	19	Bread, Graham	2
Collards	17	Graham flour	2
Lettuce	21	Wheat	2
Squash	13	Wheat bran	9
Tomato	15	Legumes	
Okra	14	Beans, dried	7
Beet roots	9	Peas, dried	9
Carrots	12		
Eggplant	16		

from Phillips, Gross and Browne (51). Uronic acids are decomposed by boiling with acid into carbon dioxide and furfural, and hence may be classed as pentosans, which they are not. The sugars and starches, which

Table 2. Uronic acid anhydride in certain foods, dry basis

Food	percent	Food	Percent
Melon, honey dew	3.60	Squash, summer	10.64
Cantaloupe	4.00	Cabbage leaves	11.16
Lima beans	4.20	Cauliflower	12.56
Peas	4.88	Radish tops	12.72
Cucumber, peeled	8.32	Kale	14.04
Asparagus stalks	9.16	Lettuce leaves, head	14.20
Asparagus tips	9.88	Beet tops	14.52
Carrots	10.24	Carrot tops	16.28

constitute high percentages of the nitrogen-free extract, are accompanied by appreciable amounts of pentosans and residual nitrogen-free extract in some foods (21).

The protein in many human foods consists almost entirely of proteids but green vegetables and fruits contain appreciable percentages of non-proteids. The percentage of nitrogen is not the same in all proteids. The usual method of ascertaining the percentage of protein is to determine nitrogen and multiply the percentage by a factor: 6.25 is required by many feed control laws, and is usually used. The factor 5.70 is sometimes used for cereals and cereal products, and the factor 6.38 for dairy products (40). The factor used should always be stated.

Composition of Some Texas Human Foods

The average chemical composition of some human foods in terms of protein, ether extract, and other constituents, from analyses made in this laboratory, are given in Table 3. The analyses were made by the methods

Table 3. Composition of some human foods, Texas analyses

	Protein, percent	Ether extract, percent	Crude fiber, percent	Nitrogen-free extract, percent	Water, percent	Ash, percent	Number averaged
Apples, dried	1.05	0.55	3.78	61.55	30.20	2.87	1
Apricots, canned, 52% solids	0.73	......	......	*21.07	77.65	.55	2
Apricots, canned, 48% liquids	.34	......	......	*16.06	83.00	.60	2
Apricots, dried	6.20	.59	5.92	76.66	3.59	7.04	1
Artichoke tubers, dried	9.9	.4	4.3	78.4	2.1	4.9	1
Asparagus, original	3.06	.21	.82	1.98	93.16	.77	2
Asparagus, dried	42.90	2.87	11.56	27.67	4.33	10.67	2
Asparagus, canned, 58% solids	4.06	......	......	*24.25	40.15	1.54	1
Asparagus tips, canned, 36% solids	4.35	......	......	*3.41	91.19	1.05	1
Barley, pearled	13.7	1.0	1.0	72.0	9.6	2.7	2
Beans, all kinds, cooked, dried	24.0	1.2	4.5	58.0	8.3	4.0	4
Beans, kidney, dried	24.25	1.24	3.90	55.50	11.07	3.98	1
Beans, lima, dried	21.54	1.10	4.99	51.75	8.24	4.42	6
Beans, navy, dried	23.59	2.30	4.92	57.75	7.58	4.46	10
Beans, pinto, dried	22.92	1.34	4.06	58.07	9.32	4.26	4
Beans, string, dried	19.06	1.69	13.72	51.93	4.28	9.33	5
Beans, string, original	1.64	.14	1.21	4.99	91.19	.83	2
Beans, canned, 57% solids	1.47	......	......	5.24	92.24	1.05	3
Beef, dried chipped	61.11	9.67	0	1.19	3.09	24.94	1
Beet roots, dried	13.04	.49	7.66	65.75	3.78	9.30	6
Beet roots, original basis	1.46	.06	.88	7.74	88.92	1.07	5
Beets, canned, 64% solids	1.17	......	......	*6.98	91.06	.79	1
Beet tops, dried	24.15	2.51	7.57	28.95	3.03	33.79	1
Blueberries, canned, 54% solids	.66	......	......	*26.79	72.33	.22	6
Blackberries, original	1.29	1.22	4.47	6.80	85.54	.68	2
Blackberries, dried	8.50	8.02	28.61	45.84	5.19	3.84	2
Bread, white	10.33	3.12	.26	48.72	35.79	1.79	7
Bread, whole wheat	10.77	3.01	.56	48.35	35.29	2.02	1
Biscuits, buttered	9.00	6.47	.16	53.31	29.27	1.39	1
Biscuits, whole wheat	10.93	1.04	2.28	77.14	5.45	3.16	1
Bread, Zweibach	12.12	11.70	.62	69.06	5.57	.93	1
Broccoli, original	3.21	.31	1.52	4.60	89.12	1.25	3
Broccoli, dried	28.11	2.70	14.99	39.85	5.05	10.96	3
Brussels sprouts, original	6.15	.47	1.95	7.81	81.94	1.68	1
Brussels sprouts, dried	32.52	2.49	10.37	41.31	4.43	8.88	1
Buckwheat flour	16.1	3.7	2.1	64.9	10.5	2.7	1
Cabbage, original	1.56	.11	.88	4.03	92.68	.75	8
Cabbage, dried	20.13	1.39	11.17	51.77	5.87	9.67	8
Carrots, original basis	1.02	.13	.98	7.86	89.17	.85	6
Carrots, dried	9.08	1.17	8.86	67.92	5.11	7.85	7
Carrots, canned, 63% solids	.74	......	......	7.53	91.05	.69	2
Celery, original	.89	.06	.84	2.99	94.10	1.12	2

*Crude fiber not determined.

Table 3. Composition of some human foods, Texas analyses—Continued

	Protein, percent	Ether extract, percent	Crude fiber, percent	Nitrogen-free, extract, percent	Water, percent	Ash, percent	Number averaged
Celery, dried	15.53	1.11	13.19	46.73	4.89	18.54	3
Chard, Swiss, dried	26.36	2.86	9.66	34.87	4.50	21.75	5
Chard, Swiss, original	2.25	.28	.77	2.70	92.36	1.64	2
Cherries, canned, 62% solids	1.03	.....	.....	21.75	76.79	.43	2
Coconut, shredded	4.61	41.30	4.13	45.71	2.62	1.63	1
Collards, original	3.02	.43	1.44	4.42	88.74	1.95	3
Collards, dried	25.46	3.61	12.07	37.09	5.53	16.24	3
Corn, canned, 80% solids	3.35	.....	.....	*24.08	71.55	1.02	1
Corn meal	10.63	3.67	1.28	73.39	9.49	1.42	8
Corn flakes	8.32	.28	.19	83.70	3.99	3.22	1
Cottonseed flour	56.97	7.22	2.14	21.61	5.56	6.50	3
Crackers	10.72	10.90	.41	68.92	5.73	3.32	1
Dates (edible part)	2.50	.....	2.48	80.19	13.29	1.52	7
Eggplant fruit, original basis	1.40	.13	.86	4.00	93.08	.53	2
Eggplant fruit, dried basis	18.50	1.68	11.84	54.08	6.35	7.16	2
Egg white	11.47	.17	.....	1.03	86.51	.85	4
Egg yolk	15.93	30.42	.....	1.05	50.89	1.71	4
Endive, original basis	1.67	.22	.99	2.71	92.52	1.89	1
Endive, dried	20.82	2.73	12.37	39.93	6.55	23.60	1
Figs, canned, 65% solids	.90	.....	.....	*53.49	45.24	.37	1
Figs, canned, liquids	.39	.....	.....	50.17	48.69	.25	1
Figs, fresh	.79	.09	1.05	15.72	81.92	.44	7
Figs, dried	11.64	2.58	15.34	60.14	5.42	4.88	6
Fig jam	.56	.....	.70	58.64	39.85	.25	1
Fig preserve, solids	.67	.....	.92	59.75	38.36	.30	1
Fig preserve, liquid	.42	.....	.....	40.76	.23	.....	1
Fig skin	.99	.60	1.10	15.49	81.90	.46	1
Flour, graham or whole wheat	12.60	1.90	2.04	70.41	11.53	1.58	4
Flour, low grade	15.99	2.16	.47	68.28	12.13	.98	2
Flour, patent or clear	12.98	.99	.32	72.29	12.80	.56	8
Flour, buckwheat	16.09	3.73	2.14	64.85	10.52	2.67	1
Flour, rye	12.61	1.90	2.16	69.77	11.75	1.81	1
Garlic, original	6.32	.17	2.79	23.13	65.96	1.65	2
Grapefruit juice	.53	.....	.....	.....	91.65	.28	6
Grape nuts	10.96	3.01	1.90	75.94	5.73	2.46	1
Grapenut flakes	11.51	1.37	2.09	76.31	5.86	2.86	1
Honey	.36	.....	.....	80.90	18.51	.23	18
Jujubes, original	1.50	.35	1.35	25.63	70.68	.47	4
Jujubes, dried	5.00	1.17	4.10	83.55	4.11	1.52	4
Kumquat fruit	1.97	.42	1.98	22.23	72.71	.69	1
Lettuce, dried	19.59	3.79	10.37	49.22	5.18	11.85	1
Lettuce, original	.98	.20	.52	2.50	95.20	.60	1
Macaroni	15.04	1.84	.40	72.50	9.31	.91	2
Milk	3.75	4.94	.....	4.44	86.09	.73	12
Milk, whole dried	28.64	20.33	.66	40.90	3.54	6.01	9
Milk, skim, dried	35.59	1.07	2.6	47.21	6.08	9.80	10
Mustard greens, original	2.57	.24	1.11	3.05	90.43	2.20	7
Mustard greens, dried	26.82	2.52	11.57	31.28	4.59	23.23	7
Mustard greens, canned, 68% solids	3.45	.....	.....	*3.75	91.50	1.30	2
Oat meal	16.20	5.07	1.49	66.64	8.66	1.94	5
Okra, original basis	2.67	.76	1.17	8.61	86.27	1.03	4
Okra, dried	18.95	1.97	8.37	58.11	5.43	7.18	3
Olives, canned, 55% solids	1.41	.....	.....	*17.85	76.47	4.27	3
Onion bulbs, original basis	.92	.15	.66	5.03	92.68	.56	1
Onion bulbs, dried basis	11.83	1.70	8.48	64.48	6.12	7.19	1
Orange juice	.64	.....	.....	.....	91.14	.36	3
Parsley, dried	19.81	3.35	11.82	46.87	4.86	13.30	2
Peaches, canned, 59% solids	.46	.....	.....	*20.20	79.00	.44	2
Peaches, canned, liquids	.28	.....	.....	*16.13	83.83	.34	1
Peanut butter	29.29	53.34	2.16	11.05	1.26	2.91	2
Peanut kernels	31.46	47.33	3.85	9.79	5.13	2.44	65
Peas	23.91	1.18	3.22	58.74	9.27	3.68	8
Peas, blackeye, dried	23.21	1.46	3.34	60.13	8.41	3.45	5
Peas, cooked, dried	24.0	1.0	3.0	58.0	10.5	3.5	3
Pecan meats	10.77	71.32	2.67	10.39	3.26	1.60	12
Pears, canned, 62% solids	.26	.....	.....	20.70	78.75	.29	1

***Crude fiber not determined.**

Table 3. Composition of some human foods, Texas analyses—Continued

	Protein, percent	Ether extract, percent	Crude fiber, percent	Nitrogen-free extract, percent	Water, percent	Ash, percent	Number averaged
Pears, canned, liquids	.19	.....	.....	18.44	81.20	.17	1
Peas, dried (381)	23.91	1.18	3.22	58.74	9.27	3.68	8
Peas, canned June, 62% solids	5.54	.....	.....	*16.80	76.50	1.24	2
Peppers, mild, dried	14.55	2.70	14.33	54.95	3.69	7.78	1
Peppers, mild, green	1.03	.19	1.02	4.05	93.16	.55	1
Pickles, cucumber, 62% solids	.66	.....	.....	*27.73	69.91	1.60	1
Pineapple, sliced, 56% solids	.64	.....	.....	*24.72	74.11	.53	1
Pineapple, canned, liquid	.36	.....	.....	6.60	92.59	.45	1
Pork, salt	9.18	65.90	.....	.....	17.22	.....	4
Potatoes, Irish, original	2.40	.07	.47	15.22	80.87	.97	9
Potatoes, Irish, dried	11.69	.35	2.21	74.74	6.13	4.89	10
Raspberries, canned, 46% solids	1.35	.....	.....	*37.83	60.51	.31	1
Raspberries, liquids	.20	.....	.....	*17.01	82.56	.23	1
Rice, brown	9.13	2.00	1.08	74.53	12.16	1.10	16
Rice polished, Honduras	9.01	.50	.40	77.02	12.57	.50	8
Rice polished	8.8	.4	.4	77.3	12.5	.6	6
Rice, puffed	7.11	.55	.31	81.87	9.78	.38	1
Rice (minute)	7.80	.32	.38	82.37	8.83	.30	1
Rice, converted	7.81	.46	.31	80.15	10.49	.78	1
Rye flour	12.6	1.9	2.2	69.7	10.5	1.8	1
Spinach, dried	29.10	2.72	8.43	27.93	4.97	26.29	5
Spinach, original	2.99	.29	.90	2.96	90.14	2.74	7
Spinach, canned, 69% solids	3.70	.....	.....	6.81	87.88	1.61	1
Squash, dried	23.71	1.95	13.67	44.76	5.18	14.73	3
Squash, original	1.23	.10	.73	2.38	95.01	.56	3
Starch	.55	.15	.17	87.61	11.49	.09	11
Strawberries, canned, 37% solids	1.01	.....	.....	34.57	63.97	.45	1
Strawberries, canned, liquids	.26	.....	.....	31.33	67.86	.55	1
Sugar, cane	.10	.02	0	99.38	0.50	.00	1
Sweet potatoes, original	1.64	.27	.91	24.38	74.27	1.04	28
Sweet potatoes, dried	5.93	.95	2.98	77.75	8.85	3.55	30
Sweet potato meal	5.32	1.35	7.20	67.84	11.61	6.67	3
Tomatoes, original	1.84	.29	.75	4.00	92.0	.92	2
Tomatoes, dried	21.80	3.39	8.97	45.97	8.44	11.43	2
Turnip greens, original	1.82	.22	1.12	3.10	92.21	1.53	3
Turnip greens, dried	31.71	2.72	11.50	30.57	6.28	18.22	8
Turnip greens, canned, 81% solids	3.93	.....	.....	54.21	40.39	1.47	1
Turnip greens, canned, 71% solids	4.01	.....	.....	3.77	90.50	1.72	1
Turnip roots, original	.88	.06	.84	4.30	93.18	.74	4
Turnip roots, dried	12.27	.84	11.71	59.74	4.83	10.61	4
Wheat bran (breakfast food)	12.85	1.95	8.91	62.70	6.12	7.47	4
Wheat flakes, whole wheat	10.34	1.11	1.85	77.03	5.34	4.33	1
Wheat, shredded	11.57	1.30	2.43	74.03	9.15	1.52	1
Wheat, shredded	9.72	1.00	2.43	77.76	5.52	3.57	1
Whole wheat cereal	13.78	1.41	2.46	70.01	10.85	1.49	1
Whole wheat cereal	16.60	1.79	2.19	66.82	10.81	1.79	1
Cream of wheat	12.42	.65	.34	74.43	11.69	.47	1
Farina	12.73	.71	.34	73.80	12.45	.47	1
Wheat bran (animal feed 1945)	16.43	4.58	9.52	52.45	10.81	6.21	7
Wheat gray shorts (animal feed)	16.12	4.06	5.42	59.05	11.47	3.88	17
Yeast, dried brewers'	49.7	1.0	4.3	30.8	5.5	8.7	7

*Crude fiber not determined.

of the Association of Official Agricultural Chemists (2). The protein is nitrogen multiplied by 6.25. Crude fiber was determined in all the foods except the canned foods. With the canned goods analyzed, the solids and the liquid portions were separated, and separate analyses made. The analyses of the solids, and the percentages of solids present are given in Table 3, but the composition of the liquid portions is given only when they are probably eaten. The percentage of crude fiber was not determined in the canned goods, but it can be estimated from the other analyses made of similar foods.

Appreciable percentages of crude fiber are found in many vegetables, as is especially evident when the analyses of the dried samples are examined. Dried asparagus averaged about 11 percent crude fiber, beans 4 to 5, beet roots 7, beet tops 7, blackberries 28 (chiefly from the seed), broccoli 15, Brussels sprouts 10, cabbage 11, carrots 9, celery 13, chard 9, collards 12, eggplant 11, endive 12, lettuce 10, mustard greens 11, okra 8, onions 8, parsley 11, peppers 14, spinach 8, squash 13, tomatoes 9, turnip greens 11, and turnip roots 11 percent.

The nitrogen-free extract of foods low in crude fiber usually consists chiefly of sugars and starches. Crude fiber is usually accompanied chiefly in the nitrogen-free extract by pentosans, uronic acids, lignin and other compounds of lower digestibility and lower food value than sugars and starches. The sugars, starches, pentosans and residual nitrogen-free extract of certain feeds are given in Table 4 and their digestibilities in Table 5 of Bulletin 437 (20). Appreciable amounts of pentosans and residual nitrogen-free extract are found in such human foods as corn meal, cowpeas, rolled oat groats, polished rice and wheat.

Some of the vegetables, on a dried basis, contain high percentages of protein. These include dried asparagus containing 42 percent protein, beet tops 24, broccoli 28, Brussels sprouts 32, cabbage 20, chard 26, collards 25, eggplant 18, endive 20, lettuce 19, mustard greens 26, okra 18, spinach 29, squash 23, tomatoes 21 and turnip greens 31 percent. The protein in such vegetables probably contains relatively high proportions of amides, and does not consist almost entirely of proteids as is the case with most human foods.

Analyses of some breakfast foods, including corn flakes, grape nuts, oat meal, wheat flakes, shredded wheat, cream of wheat, farina and wheat bran are also in Table 3.

The average calcium, magnesium, phosphorus, and potash (K_2O) content found in Texas analyses of some foods are given in Table 4 (54a). Some

Table 4. Mineral constituents of some human foods, Texas analyses

	Calcium Ca percent	Magnesium Mg. percent	Phosphorus P percent	Potash K_2O percent
Asparagus, original	.05	.02	.01	.18
Asparagus, dried	.60	.23	.18	4.61
Beans, all kinds, cooked, dried	.21	.19	.45	1.77
Beans, lima, dried	.12	....	.44	....
Beans, navy, dried	.17	.15	.42	....
Beans, string, dried	.43	.31	.35	....
Beet roots, dried	.17	.20	.29	3.54
Beet roots, original basis	.02	.02	.03	....
Beet top, dried	1.04	1.27	.32	3.83
Blackberries, dried	.31	.18	.19	1.40
Broccoli, original	.06	.11	.01	....
Broccoli, dried	1.08	.25	.29	....
Cabbage, original	.08	.02	.04	....
Cabbage, dried	.90	.22	.42	....
Carrots, original basis	.03	.02	.04	....

Table 4. Mineral constituents of some human foods, Texas analyses—Continued

	Calcium Ca percent	Magnesium Mg. percent	Phosphorus P percent	Potash K_2O percent
Carrots, dried	.35	.18	.38	4.14
Celery, dried	...	...	...	6.13
Chard, Swiss, dried	.73	.74	.35	...
Chard, Swiss, original	.07	.07	.03	...
Coconut, shredded	.04	...	.14	...
Collards, original	.21	.04	.04	...
Collards, dried	2.28	.35	.45	3.42
Cottonseed flour	.20	.60	1.22	...
Cucumber, dried	.58	.39	.56	5.14
Dates (edible part)	.07	.06	.07	.99
Eggplant, fruit, original basis	.01	.02	.03	.23
Eggplant fruit, dried	.16	.24	.43	3.35
Egg yolk	.11	.02	...	...
Figs, fresh	.05	.02	.02	.25
Flour, graham or whole wheat	.06	.07	.29	...
Flour, patent or clear	.04	...	.09	...
Garlic, original	.16	.04	.16	.69
Kumquat fruit	.05			.29
Lettuce, dried	.87	.42	.44	...
Macaroni	.04	.07	.15	...
Milk, skim, dried	1.22	.13	.96	...
Mustard greens, original	.19	.04	.04	...
Mustard greens, dried	2.00	.40	.48	5.69
Oatmeal	.08	.14	.42	...
Okra, original basis	.11	.04	.04	...
Okra, dried	1.08	.38	.39	...
Onion bulbs, original basis	.04	.01	.04	...
Onion bulbs, dried basis	.45	.16	.49	...
Parsley, dried	1.34	.31	.36	...
Peanut kernels	.09	.19	.33	...
Peas, blackeye, dried	.08	.18	.43	...
Peppers, mild, dried	.22	.12	.23	2.18
Potatoes, Irish, original	.02	.03	.05	...
Potatoes, Irish, dried	.09	.14	.23	...
Rice, polished	.01	.02	.03	...
Spinach, dried	.95	.92	.56	7.15
Spinach, original	.15	.11	.06	.84
Squash, dried	.38	.29	.59	...
Squash, original	.02	.01	.03	...
Sweet potatoes, original	.04	.03	.04	2.28
Sweet potatoes, dried	.14	.10	.15	...
Tomatoes, original	.02	.02	.06	...
Tomatoes, dried	.12	.16	.30	3.40
Turnip roots, original	.04	.02	.02	...
Turnip roots, dried	.48	.22	.31	...
Turnip greens, dry basis	2.92	...	.61	Protein
Turnip greens, Shogoin, dry basis, very young	2.87	...	.63	38.5
Ditto—young	3.02	...	.41	33.4
Ditto—market size	3.10	...	.45	29.9
Ditto—later market size	3.36	...	.35	27.1
Ditto—mature	3.87	...	.21	22.3

of the breakfast foods contained salt (NaCl) as follows: shreddies (shredded wheat) 2.3 percent, wheaties 3.2, grape nut flakes 2.0 percent, grape nuts 1.9 percent, and corn flakes 2.4 percent.

Compilations of Analyses of Human Foods

The average composition for protein, fat, energy, and other constituents of human foods has been given in a number of publications. The compilation of Atwater and Bryant, revised 1899 and 1906 (6) has been widely quoted, and the analyses given in many publications were taken from this publication. More recently (1940) average values have been given by

Chatfield and Adams (12). Tables of Food Composition (1945) (11) gives not only averages for the protein and energy values, but also minerals and vitamins. Averages are also given by H. C. Sherman (54), Bridges (8), McCance and Widowson (46a), Hutchinson (38), and others (38).

Digestibility of Human Foods

In estimating the metabolizable energy or the net energy of foods or feeds, it is necessary to consider their digestibility. The apparent digestibility is ascertained with experimental animals or humans by determining the income of the various nutrients in the food eaten and the outgo in the corresponding amount of excrement. Human excrement contains appreciable percentages of bacteria and metabolic products (44) as well as the undigested residues of the food. On account of the presence of metabolic products, the actual digestibility is therefore somewhat greater than the apparent digestibility. The bacteria live upon unabsorbed food materials, and therefore represent undigested food, in one sense of the term. The metabolic products contain energy which originally constituted part of the food energy. The energy in solid and liquid excrement must be considered in ascertaining the metabolizable or the net energy of foods or feeds. The apparent digestibility can therefore well be used in estimating the energy value of the food.

Texas Digestion Experiments

Eight digestion experiments with two human subjects on each food were carried out at the Texas Station. The method of Grindley, Mojonnier, and Porter (37), was followed in the preparation of the foods. The subjects received bread, butter, milk and the food to be tested.

The oat meal was cooked according to the directions of the manufacturer and while hot put into hot pint fruit jars which were then sealed and placed in cold storage. Samples for analysis were taken at intervals while filling the jars. The vegetables were washed and cooked approximately 30 minutes, or until tender, seasoned with salt, put in fruit jars and sterilized in a steam oven for one hour.

Each food was prepared immediately before the digestion experiment was begun. A jar for each subject was warmed in boiling water for 30 to 45 minutes before serving. Each jar was weighed before and after the food had been removed so as to ascertain the weight of the food eaten. The bread was put into half gallon jars and kept in cold storage. The butter in pats was put in jars and kept in cold storage. A pint of milk was allowed for each meal.

The milk was secured in the morning, thoroughly mixed and a pint sample taken for analysis. The other portions were weighed before and after meals to ascertain the amount of milk drunk.

The sterilized foods kept in good condition. The subject was given the weighed jars as needed and ate what food he wished, the meat and vegetables having been warmed for 30 minutes in a steam bath to make them more palatable. If any food remained in the jar it was weighed.

The samples for analysis were weighed and dried in a water bath for about 48 hours, then exposed to room temperature and moisture before weighing before preparation for analysis.

The subjects had a three-day preliminary period and a two-day collection period. They were furnished covered pails fitted with a weighed evaporating dish and the excrements were brought to the laboratory and dried. The dishes and dried excrements were then weighed and the weights of the dishes subtracted. The excrements were combined and ground for analysis.

Results of the Texas Experiments

The composition of the foods used in the digestion experiments are given in Table 5, and the digestibility in Table 6. The coefficients of digestibility are also incorporated in the averages in Table 8.

Table 5. Composition of foods used in human digestion experiment

	Protein percent	Ether extract percent	Crude fiber percent	Nitrogen-free extract percent	Water percent	Ash percent
Beans, string	1.16	.13	1.04	4.40	92.44	.83
Cabbage, boiled	1.09	.08	.81	4.18	93.33	.51
Collards	3.13	.54	1.51	3.52	88.44	2.36
Oatmeal, cooked	2.12	0.29	0.21	9.56	87.38	.44
Bread, average of 3 samples	10.90	3.26	.30	47.63	36.00	1.91
Butter, average of 3 samples	....	82.04	....	....	....	....
Milk, average of 8 samples	3.93	5.27	0	5.13	84.93	.74

Table 6. Percentage digestibility of the constituents of some human foods —Texas experiments

	Protein percent	Ether extract percent	Crude fiber percent	Nitrogen-free extract percent
Oat meal	75	64	57	100
Oat meal	94	100	0	100
Average	85	82	29	100
String beans	26	100	80	77
String beans	59	100	88	92
Average	43	100	84	85
Cabbage	48	100	36	75
Cabbage	39	100	67	84
Average	44	100	52	80
Collards	66	100	82	0*
Collards	72	100	73	45
Average	69	100	78	45

*Excluded from average.

Average Digestibility of Foods

In connection with the work here reported, human digestion experiments were compiled and averaged so far as they were available, as had previously been done for digestion experiments with ruminants (19), with chickens (25) and with rats (27).

The average digestibility for animal and vegetable fats and oils by human experiments are given in Table 7, including some digestion experiments with rats. Coefficients of digestibility for other foods and some mixtures are given in Table 8. Table 9 contains the references to the experiments from which the data in Tables 7 and 8 are derived.

Table 7. Average digestibility of fats and oils, compiled

	Ether extract, percent	Number averaged	References Table 9
Almond oil	97	4	39
Apricot oil	98	4	44
Brazil nut oil	96	3	39
Beef fat	89	10	34
Brisket fat	97	7	37
Butter, cow	93	19	34, 56, 82
Butter, goats	98	4	38
Butternut oil	95	3	39
Cantaloupe seed	98	3	44
Charlock oil	99	4	42
Cherry kernel oil	98	4	44
Chicken fat	97	8	37
Coconut oil	98	7	34
Coconut butter	100	2	50
Corn oil	97	7	42
Corn oil	94	7	83
Corn oil, hydrogenated, m. p. 33° C	99	5	83
Corn oil, hydrogenated, m. p. 43° C	95	5	83
Corn oil, hydrogenated, m. p. 50° C	81	5	83
Corn oil and other oil	93	27	37, 82
Cottonseed oil	98	7	36
Cottonseed oils, blended	95	10	83
Cottonseed oil, hydrogenated	96	5	52, 62
Cottonseed oil, hydrogenated, m. p. 35° C	97	....	83
Cottonseed oil, hydrogenated, m. p. 46° C	95	....	83
Deer fat	82	3	83
Goose fat	95	7	37
Hard palate fat	94	3	36
Hickory nut oil	99	4	39
Horse fat	94	3	38
Kid fat	95	3	38
Lard	95	13	34, 52, 54
Lard substitute	96	2	57
Margarin	98	4	56
Mustard seed oil (Japanese)	96	3	42
Mutton fat	81	7	34
Nut butter and milk fat	95	22	55
Oleo oil	97	8	38
Olive oil	98	10	36
Ox marrow fat	94	4	38
Ox tail fat	97	3	38
Peach kernel oil	97	3	44
Peanut oil	98	7	36
Peanut oils	97	9	83
Peanut oil, hydrogenated, m. p. 37° C	98	5	83
Peanut oil, hydrogenated, m. p. 43° C	97	5	83
Peanut oil, hydrogenated, m. p. 50° C	92	4	83
Peanut oil, hydrogenated, m. p. 52.4° C	79	3	83
Pecan oil	97	4	39
Pumpkin seed oil	98	2	44

Table 7. Average digestibility of fats and oils, compiled—Continued

	Ether extract, percent	Number averaged	References Table 9
Rape seed oil	99	4	42
Sesame oil	98	5	36
Soybean oil	98	7	42
Sunflower seed oil	97	4	42
Tea seed oil	91	1	62
Tomato seed oil	96	3	44
Turtle, green, fat	99	3	39
Walnut (black) oil	98	4	39
Walnut (English) oil	98	3	39
Watermelon seed oil	95	3	83
Average	96.0		

Table 8. Average digestibility of human foods other than fats and oils, compiled

	Protein, percent	Ether extract, percent	Carbohydrates, percent	Number averaged	References Table 9
Aleurone	97	....	97	1	68
Aleurone biscuits	91	....	97	2	68
Almonds	84	88	92	6	24, 64
Algae, dried	16	35	68	4	31
Apples	72	86	95	9	27
Apples, dried (rats)	0	36	94	1	84
Apple sauce	19	98	99	2	77
Arrowhead, soybean sauce	90	72	98	1	31
Artichoke tubers (rats)	27	0	90	1	84
Asparagus, dried (rats)	84	65	81	2	84
Bacon	92	96	....	6	10
Bananas	75	82	94	8	27
Barley	69	....	97	2	13
Barley, rolled, and soybean sauce	69	....	99	2	31
Barley and beef soup	51	60	93	1	31
Barley bread and butter	78	95	91	1	59
Beans, navy, cooked (rats)	74	61	92	4	84
Beans	80	80	96	3	9
Beans, kidney	77	60	94	8	32
Beans, navy (calc.)	76	41	94	5	9
Beans, navy	78	51	96	6	32
Beans, soybean sauce	66	36	90	2	31
Beans, string	43	100	85	2	85
Beans, string (rats)	53	21	89	2	84
Beef as hamburger (calc.)	96	96	....	2	17
Beef, fat shoulder (boiled)	97	97	....	3	33
Beef, lean, fried	97	98	....	3	33
Beef, lean round (boiled 1 hr. 80-85° C.)	97	89	....	5	33
Beef, lean (boiled 2 hr. in 80 to 85° C.)	97	90	....	5	33
Beef, lean (boiled 3 hr. in 80 to 85° C.)	99	97	....	2	33
Beef, lean round (roasted)	99	99	....	3	33
Beef, ribs (roasted)	99	99	....	7	33
Beef, roasted	98	88	....	5	14, 49
Beef, round (pan boiled)	98	98	....	3	33
Beet roots	72	100	97	3	77
Beet roots (rats)	48	25	92	5	84
Brazil nut	85	89	94	3	27
Bread (aleurone layer 15%, sugar 10%)	86	....	96	2	68
Bread, 2/3 wheat, 1/3 barley	82	94	99	1	74
Bread, black	83	72	73	3	51
Bread, black	66	....	86	2	71
Bread, brown (coarse)	79	....	....	4	73

Table 8. Average digestibility of human foods other than fats and oils, compiled—Continued

	Protein, percent	Ether extract, percent	Cabro-hydrates, percent	Number averaged	References Table 9
Bread, graham	79	65	92	40	6, 19, 20, 22, 26, 28, 30, 70
Bread, 2/3 wheat, 1/3 maize	87	95	99	1	74
Bread, Pumpernickel	48	....	90	1	68
Bread, war, 1917	89	96	99	1	74
Bread, wheat and rye with yeast	81	....	....	4	14
Bread, 70% milled from fine rye and wheat flour	86	95	98	2	70
Bread, white	87	75	98	77	6, 14, 19, 22, 26, 28, 30, 50, 51, 61, 70, 71, 73, 74
Bread, white (rats)	85	91	99	4	84
Bread, bran and flour	86	....	94	3	30
Bread, germ flour	90	....	98	3	30
Bread, white (70% milled)	94	97	99	2	70
Bread, white (finely ground zwiebach flour, 70% milled)	81	....	97	2	68
Bread, white flour (75% milled)	88	....	....	12	66
Bread, white flour (80% milled)	87	....	....	6	61
Bread, white flour (85% milled)	82	....	....	6	66
Bread, 80% milled (corn 82%, flour 18%)	85	....	....	6	66
Bread, white flour (20% starch)	84	....	98	3	17
Bread, white, war	89	96	99	1	75
Bread, whole wheat	83	64	95	40	6, 14, 19, 22, 26, 28, 30, 34, 61, 73
Bread, zwiebach aleurone	86	....	97	2	68
Bread, zwiebach, white flour	79	....	98	4	68
Bread, zwiebach	82	....	98	10	68
Bread, zwiebach with 15% peanut grits	90	....	98	4	68
Bread, graham and milk	90	95	94	29	14, 22, 26
Bread, white and milk	93	95	97	26	22, 26
Bread and meat	92	90	98	3	14, 17
Bread, cereal and milk	93	95	98	25	11, 17, 19, 22
Bread, milk, bananas	91	95	98	23	32
Bread, meat, milk, eggs, vegetables	93	95	98	30	2, 16, 20, 24
Bread, meat, milk, vegetables	93	96	97	43	17, 20, 28, 33
Bread, rice, meat, fish, vegetables	81	....	97	6	31
Bread, eggs, beans, potatoes	83	96	95	2	9
Broccoli (rats)	54	36	81	1	84
Buckwheat, meat extract, soybean sauce	75	43	97	2	31
Buckwheat flour (rats)	83	86	95	2	84
Burdock root, edible	25	....	94	1	31
Cabbage	46	64	82	3	77, 85
Cabbage, savoy	82	94	85	2	50, 71
Cabbage (rats)	58	68	85	5	84
Cakes, aleurone	86	....	96	8	68
Cakes, English Albert	77	....	98	4	68
Carrots	61	94	82	2	14, 71
Carrots (rats)	26	80	90	4	84
Carrots, soybean sauce	27	49	96	1	31
Celery (rats)	67	67	85	2	84
Chard, Swiss (rats)	71	60	62	3	84
Cheese	93	95	....	1	9
Cheese, high rennet (at 32° F.)	95	96	....	3	46
Cheese, low rennet (at 32° F.)	95	96	....	4	46
Cheese, high rennet (at 40° F.)	99	98	....	6	46
Cheese, low rennet (at 40° F.)	98	96	....	7	46
Cheese, high rennet (at 60° F.)	98	96	....	3	46
Cheese, low rennet (at 60° F.)	99	96	....	3	46
Cheese, Camembert	86	85	....	2	46

Table 8. Average digestibility of human foods other than fats and oils, compiled—Continued

	Protein, percent	Ether extract, percent	Carbohydrates, percent	Number averaged	References Table 9
Cheese, cottage	94	95	97	4	10, 46
Cheese, green	96	92	....	2	46
Cheese, old cold storage	94	92	....	2	46
Cheese, Roquefort	94	91	....	1	46
Cheese, skim milk	97	89	....	1	46
Cheese, Swiss	92	91	....	1	46
Chestnut flour	56	63	98	2	8
Chicken	97	97	....	4	5
Chicken loaf	97	99	100	2	12
Coconut	75	92	97	1	27
Coconut oil meal (rats)	64	97	72	2	84
Cocoa	7	64	....	12	81
Collards	67	100	45	2	67
Collards (rats)	73	52	80	2	84
Corn	85	....	93	1	71
Corn bread	60	....	96	3	35
Corn, green	84	41	97	1	70
Corn meal	76	58	98	3	7, 13, 14
Corn meal (rats)	80	79	98	6	85
Corn meal soup	90	86	96	1	55
Corn meal and wheat flour soup	90	86	96	2	55
Corn meal porridge	76	85	95	1	55
Corn meal, white, raw (in frozen pudding)	....	....	99	3	45
Corn meal, milk, apples, butter	77	....	99	17	65
Cottonseed meal	78	100	60	5	72
Crackers, soda	91	100	99	10	25
Crackers, milk, butter	95	97	97	10	25
Cream	....	97	....	7	37
Dates	70	80	94	6	27
Duck meat	91	98	....	4	5
Eggs, all	94	95	....	5	14, 17, 37, 79
Eggs, soft boiled	96	94	....	1	79
Eggs, raw	97	96	....	1	79
Eggs (calc.)	91	89	....	3	17
Eggs, hard boiled	97	99	....	1	14
Egg yolk	....	94	....	6	37
Eggplant (rats)	44	69	88	3	84
Eggplant, soybean sauce	....	....	87	1	31
Farina	73	....	99	3	13
Farina (in frozen pudding)	....	....	100	4	45
Fern, soybean sauce	20	....	91	1	31
Feterita bread	51	....	97	8	35
Feterita mush	48	....	99	4	35
Figs	71	88	97	1	27
Fish, butterfish	92	86	....	3	40
Fish, cod	96	97	....	4	5
Fish, dried	99	90	....	1	31
Fish, grayfish	93	94	....	8	40
Fish, haddock	99	91	....	1	14
Fish, dried (Kusaya-aji)	89	47	....	1	31
Fish, mackerel	93	95	....	3	37
Fish, salmon	95	95	....	4	5, 31
Fish, shellfish	97	85	....	1	31
Fish, soybean sauce	95	87	....	3	31
Fish, milk, cereal, bread	94	97	98	7	20
Flour, raw graham (in frozen pudding)	....	....	97	3	45
Flour, raw patent (in frozen pudding)	....	....	100	3	45
Flour, wheat flour soup	91	88	97	1	55
Flour, low grade flour soup	91	86	96	1	55
Food, concentrated army, German 1917	80	....	97	4	68
Gourd, dried, soybean sauce	31	....	89	2	31
Grapes	45	68	96	1	27
Grapenuts	72	....	92	4	4, 7
Ham, fresh fat (roasted)	99	99	....	4	33
Hominy	75	....	....	1	7
Kafir bread, hard	59	....	98	7	35

Table 8. Average digestibility of human foods other than fats and oils, compiled—Continued

	Protein, percent	Ether extract, percent	Carbo-hydrates, percent	Number averaged	References Table 9
Kafir bread, soft	51	....	96	7	35
Kafir mush	48	....	96	3	35
Kaoliang bread	19	....	96	9	35
Kaoliang mush	12	....	96	8	35
Lentils	60	....	84	1	44
Lettuce (rats)	61	64	84	1	84
Lotus rhizone, soybean sauce	63	....	93	1	31
Macaroni	84	56	97	3	30
Macaroni, Calc	91	100	67	6	30
Macaroni (rats)	94	85	99	2	84
Macaroni or vermicelli, beef extract, soybean sauce	91	81	99	4	31
Meat	98	....	....	1	71
Meat, raw	93	81	....	1	58
Milk	92	97	89	9	1, 14, 17, 48, 71
Milk (calc.)	100	99	100	4	17, 60
Milo bread	40	....	96	8	35
Milo mush	34	....	98	4	35
Mushroom, soybean sauce	19	....	81	1	31
Mustard greens (rats)	70	68	69	2	84
Mutton leg (roasted)	98	98	....	4	33, 47
Nerka (breakfast food)	81	....	98	1	13
Okra (rats)	39	45	82	4	84
Oatmeal or rolled oats	83	83	97	15	7, 13, 22, 64, 85
Oatmeal bread (2/3 wheat, 1/3 oatmeal)	88	94	99	1	74
Oatmeal, bread and butter	64	95	22	1	59
Olives	65	78	91	3	27
Orange meat	76	....	95	1	13
Peanuts	89	88	92	1	27
Peanut butter	91	88	92	1	27
Pears	78	90	97	2	27
Peas	83	73	96	5	10, 20
Peas, cooked in soft water	90	88	....	1	60
Peas, cooked in hard water	83	89	....	1	60
Peas, dry	83	36	96	1	14
Peas, clay	74	63	88	7	32
Peas, lady	83	65	95	14	32
Peas, whipperwill	70	69	87	12	32
Peas, blackeye, cooked (rats)	78	77	94	3	84
Pecans	72	88	93	5	27
Persimmons	84	80	92	1	27
Pork, roast	99	96	....	3	76
Potatoes, white	75	80	98	10	15, 31, 71, 77
Potatoes, white (rats)	52	12	92	5	84
Potatoes, sweet, see sweet potato					
Prunes	80	88	96	1	27
Pumpkin, soybean sauce	89	67	99	1	31
Pumpkins, dried (rats)	47	78	94	3	84
Rice	71	97	97	8	10, 31, 71
Rice, cooked (rats)	84	71	99	2	84
Rice and meat extract	80	93	99	1	14
Rice bread—2/3 wheat, 1/3 rice	90	96	99	1	74
Rice, barley, vegetables	74	97	97	2	31
Rice, meat extract, soybean sauce	80	45	99	3	31
Rice, barley, meat, fish, vegetables	70	....	97	5	31
Rice bread	69	90	93	74	50, 67, 68, 70, 72
Rye bread, black	51	....	92	31	68
Rye bran, coarse, in bread	51	....	83	2	69
Rye bran, in bread	62	....	91	4	69
Spinach (rats)	72	30	73	3	84
Squash (rats)	44	50	75	2	84
Starch, raw corn	....	....	100	4	45
Starch, raw potato	....	....	81	4	45
Starch, raw rice	....	....	100	2	45
Starch, raw wheat	....	....	100	3	45
Starch, corn (rats)	....	....	99	12	84

Table 8. Average digestibility of human foods other than fats and oils, compiled—*Continued*

	Protein, percent	Ether extract, percent	Carbo-hydrates, percent	Number averaged	References Table 9
Sweet potatoes (rats)	34	67	97	15	84
Sweet potatoes, soybean sauce	10	54	98	2	31
Toast	85	....	97	2	9
Tomatoes, dried (rats)	35	52	81	1	84
Toco, soybean sauce	50	47	95	1	31
Turnip greens (rats)	64	72	74	2	84
Turnip roots (rats)	34	92	89	1	84
Veal	94	98	....	3	63
Veal, roasted	99	98	....	6	33
Walnut	77	85	94	9	27
Wheat germ	86	....	98	1	13
Wheat, rolled, breakfast food	79	....	95	2	7, 13
Wheat, shredded, breakfast food	58	....	....	1	7
Wheat, breakfast food	72	....	96	3	13
Wheat, breakfast food	73	71	89	3	30
Wheat (rats)	78	61	92	3	84
Wheat bran, coarsely ground	28	....	56	8	43
Wheat bran, finely ground	45		57	8	43
Wheat bran (rats)	74	47	60	10	84
Wheat bran bread	44	....	63	2	68
Wheat shredded, bacon, orange juice	80	97	....	5	53
Yam, soybean sauce	60	48	97	1	31
Yeast, dried brewers' (rats)	80	0	96	12	84

Table 9. References to human digestion experiments averaged in Tables 7 and 8

1. Conn. Exp. Sta. (Storrs) Report 1896
2. Conn. Exp. Sta. (Storrs) Report 1897
3. Conn. Exp. Sta. (Storrs) Report 1901
4. Conn. Exp. Sta. (Storrs) Report 1905
5. Conn. Exp. Sta. (Storrs) Report 1905
6. Maine Exp. Sta. Report 1898
7. Maine Exp. Sta. Report 1905 Bul. 118
8. Maine Exp. Sta. Bul. 108, 131
9. Minnesota Exp. Sta. Bul. 74
10. Minnesota Exp. Sta. Bul. 92
11. Minnesota Exp. Sta. Bul. 111
12. Texas Agr. Exp. Sta. Bul. 163
13. Ontario Agri. College, Canada, Bul. 162
14. U.S.D.A. Office Exp. Sta. Bul. 21
15. U.S.D.A. Office Exp. Sta. Bul. 43
16. U.S.D.A. Office Exp. Sta. Bul. 44
17. U.S.D.A. Office Exp. Sta. Bul. 53
18. U.S.D.A. Office Exp. Sta. Bul. 84
19. U.S.D.A. Office Exp. Sta. Bul. 85
20. U.S.D.A. Office Exp. Sta. Bul. 89
21. U.S.D.A. Office Exp. Sta. Bul. 98
22. U.S.D.A. Office Exp. Sta. Bul. 101
23. U.S.D.A. Office Exp. Sta. Bul. 107
24. U.S.D.A. Office Exp. Sta. Bul. 117
25. U.S.D.A. Office Exp. Sta. Bul. 121
26. U.S.D.A. Office Exp. Sta. Bul. 126
27. U.S.D.A. Office Exp. Sta. Bul. 132
28. U.S.D.A. Office Exp. Sta. Bul. 143
29. U.S.D.A. Office Exp. Sta. Bul. 149
30. U.S.D.A. Office Exp. Sta. Bul. 156
31. U.S.D.A. Office Exp. Sta. Bul. 159
32. U.S.D.A. Office Exp. Sta. Bul. 187
33. U.S.D.A. Office Exp. Sta. Bul. 193
34. U.S.D.A. Bulletin 310
35. U.S.D.A. Bulletin 470
36. U.S.D.A. Bulletin 505
37. U.S.D.A. Bulletin 507
38. U.S.D.A. Bulletin 613
39. U.S.D.A. Bulletin 630
40. U.S.D.A. Bulletin 649
41. U.S.D.A. Bulletin 681
42. U.S.D.A. Bulletin 687
43. U.S.D.A. Bulletin 751
44. U.S.D.A. Bulletin 781
45. U.S.D.A. Bulletin 1213
46. U.S.D.A. Bur. Animal Industry Cir. 166
47. U.S.D.A. Farmer's Bull. 526
48. U.S.D.A. Farmer's Bull. 1207
49. Exp. Sta. Record 10 :662
50. Exp. Sta. Record 11 :375-376
51. Exp. Sta. Record 11 :478-9
52. Jour. Biol. Chem. 23 :505-11
53. Jour. Biol. Chem. 38 :43-48
54. Jour. Biol. Chem. 23 :508
55. Exp. Sta. Record 10 :180-181
56. Exp. Sta. Record 11 :659-660
57. Exp. Sta. Record 12 :274
58. Exp. Sta. Record 14 :71
59. Exp. Sta. Record 14 :1102
60. Exp. Sta. Record 15 :64
61. Minnesota Exp. Sta. Bul. 54
62. U.S.D.A. Bul. 1033
63. Jour. Ag. Res. 6 :883-4
64. Jour. Biol. Chem. 57 :308-10
65. Jour. Home Econ. 17 :75-8
66. Revue general des Sciences, 56 :614
67. Landwirtschaftlich Versuchstationen. 79-80 :457-458
68. Untersuchung uber das Soldaten Brot. Berlin 1897 128-172, 214-218
69. Skandinavische Archiv fur Physiologie. 33 :64-67
70. Skandinavische Archiv fur Physiologie. 28 :168-169
71. Skandinavische Archiv fur Physiologie. 27 :280-285
72. Zeitschrift fur Untersuchung der Nahrungs and Genussmittle 26 :109
73. Jour. of Hygiene 12 :132-133
74. Lancet Vol. 11 for 1917 :724-726

Table 9. References to human digestion experiments averaged in Tables 7 and 8—Continued

75. Report of Food Commission of the Royal Society 8-24
76. Zeitschrift fur Biologie N. S. 24:377-406
77. American Journal of Physiology. 10:81-99
78. Archive fur Physiologie, 38:614-616
79. Deutsche Medizinische Wochenschrift. 53:2308-10
80. Zeitschrift Untersuchung Nahrungs und Genussmittle. 7:529-545
81. Archive fur Hygiene. 60:175-190
82. American Jour. of Diseases of Children. 18:158-172
83. U.S.D.A. Bul. 1033
84. Texas Agr. Exp. Sta. Bul. 678
85. This bulletin

The average digestibility of many of the fats and oils, Table 8, is over 95 percent and for most of them it is 96 percent or over. Fats having lower digestibilities are cow butter 93.1 percent, corn oil with other fat 93 percent, hard palate fat 93.7 percent, lard 95 percent, ox marrow fat 93.5 percent, nut butter fat 94.9 percent, and tea seed oil 91.2 percent. The digestibility is less than 90 percent for beef fat, 88.9 percent, and mutton fat 80.5 percent. According to Cowgill (13), if the melting point of edible fats is such that they are liquefied in the alimentary tract, they are digested and absorbed to about the same extent; the differences are of no practical significance. The digestibility of the ether extracts listed for many foods in Table 8 is lower than that of the fats and oils cited in Table 7. This is probably due partly to the low percentages of ether extract in the foods in question, causing exaggerations of small errors as has been shown in digestion experiments with chickens (24) and with rats (27). The presence of metabolic fat may also have produced low apparent digestibility. The actual digestibility of fats and oils contained in foods is probably higher than is reported in Table 8.

Some of the human digestion experiments were conducted with simple mixtures, but with other experiments complicated diets were used. As pointed out, with chickens (24) and with rats (27), digestibilities of individual foods calculated from complicated diets are more variable than when simple mixtures are used. The average digestibilities of some of these mixtures are given in Table 8.

Adequate numbers of human digestion experiments have been made with many foods, such as meats, fish, bread, fats and oils, and some cereals. For other foods, the number of experiments is not sufficient; this includes especially nuts, fruits, and many vegetables. As pointed out (27), digestion experiments with rats may be used as an aid in estimating the digestibility of some human foods.

Table 8 contains also the average digestibilities of certain mixtures, which were taken to have some value in ascertaining the digestibility of human foods.

The average digestibilities of groups of foods from Table 8 are given in Table 12 together with other data which will be discussed on a subsequent page.

The average digestibility of the mixed diet in Table 11 is that given by Atwater, by Sherman, and by others.

Digestibility of Crude Fiber

The number of human experiments in which the digestibility of crude fiber was determined is comparatively small. Jaffa (39) and Oshima (50) report experiments in which the digestibility of crude fiber and nitrogen-free extract were determined in fruits, nuts and vegetables. Some of them are listed in Table 10. The digestibility of crude fiber in nuts, fruits and vegetables is fairly high, being about 75 percent. The digestibility of the crude fiber in entire wheat or rye bread is about 50 percent, while in wheat bran it may be appreciably lower.

Table 10. Digestibility of crude fiber in some human foods and mixtures

	Percent		Percent
Apple sauce	95	Celery, cabbage, carrots	63
Beets	84	Celery, cabbage, carrots	47
Rye bran in bread	77	Bread, dry fruit, oil	44
Bread, wheat and rye	45	Bread, fruit, oil	63
Bread, white	53	Rice, barley, vegetables	76
Bread, whole wheat	45	Rice, vegetable, fish	82
Bread	44	Rice, vegetables, meal	91
Cabbage	77	Wheat and rye bread	37
Corn, green	59	Wheat and rye bread	50
Potatoes	74	Wheat and rye bread	30
Wheat bran, finely ground	70	Entire rye bread	55
Fruit and nuts, 16 exp.	75	Entire rye bread	44
Fruit and nuts, 11 exp.	82	Entire wheat bread	45
Fruit and nuts, 2 exp.	77	Rye bread	46
Fruit and nuts, 1 exp.	77	Rye bread	36
Potatoes, glutin, fat, beer	78	Wheat bread	53
Potatoes, fat, beer	79	Wheat bread	53

Metabolizable Energy

Metabolizable energy is the energy of the food less the energy in the excrement, both fecal and urinary, and, in case of ruminants, the energy in gases produced by fermentation. Metabolizable energy includes all the energy of the food which might possibly be used by the animal.

The calories of energy in human foods are, at the present time, expressed approximately in terms of metabolizable energy (4, 8). Atwater, in 1895 (4), used Rubners factors for the fuel value of digestible nutrients for foods, namely 4.1 calories per gram of protein and of carbohydrates and 9.3 calories per gram of fat. These are the isodynamic values or food values of nutrients as calculated by Rubner and as discussed by Atwater (3) in 1887. These values at that time were considered to be tentative (4) and not to apply with exactness to the nutrients of all food materials, as they represented the results of only a small number of experiments made up to that time, nearly all with dogs. The metabolizable energies of digested fat or carbohydrates are practically the same as their heat of combustion. With protein, however, part of the energy is excreted in urea, so that the metabolizable energy is 4.1 calories per gram, compared with 5.7 calories per gram for heat of combustion of protein.

The fuel values of the different food materials averaged by Atwater and Bryant 1899 (6) were calculated by use of the factors of Rubner, which allow 4.1 calories for a gram of protein, the same for a gram of carbohydrates, and 9.3 calories per gram of fats. These amounts correspond to 18 calories of energy for each hundredth of a pound of protein and of carbohydrates and 44.2 calories for each hundredth of a pound of fat in the given food material. The assumption was made that the nutrients are completely digested, which is not correct.

Atwater and Bryant 1899 (5) after allowing for average digestibility, arrived at the values of 4.0 calories per gram for total protein and total carbohydrates and 8.9 calories per gram for total fats in a mixed diet of animal and vegetable origin. The protein of fruits and vegetables would have a lower value than other foods on account of the high percentages of non-proteids in the protein, 40 or 60 percent respectively being the values assumed.

H. C. Sherman 1911 (53) and 1941 (54) used the values of 4 calories per gram of protein and carbohydrates and 9 calories for fats as representing the approximate physiological fuel values of these constituents in all human foods, and these values are also used by Chatfield and Adams (12) and in Tables of Food Composition (11), and are discussed by Maynard (46). These values were derived by Sherman (54) from the following considerations: The metabolizable energy of digested protein was considered to be 4.35 calories per gram, of fats, 9.45 calories per gram, and of carbohydrates 4.1 calories per gram. The approximate average digestibility of the nutrients in a mixed animal and vegetable diet were considered to be 98 percent for carbohydrates, 95 percent for fats and 92 percent for protein. The approximate physiological fuel values in an average mixed diet were then calculated to be:

Protein	$4.35 \times .92 = 4$ calories per gram
Fats	$9.45 \times .98 = 9$ calories per gram
Carbohydrates	$4.1 \times .98 = 4$ calories per gram

The average coefficients of digestibility of classes of foods according to Atwater and Bryant (5) as based on the limited data then available, are given in Table 11. The approximate physiological fuel values for the constitutents, calculated for the classes of food by the method given above, are also given in Table 11.

Table 11. Average coefficients of digestibility of foods in a mixed diet (Atwater)

	Digestibility			Physiological fuel value, calories per gram		
	Protein	Fat	Carbohydrates	Protein	Fat	Carbohydrates
Animal foods	.97	.95	.98	4.2	9.0	4.0
Cereals and breadstuffs	.85	.90	.98	3.7	8.5	4.0
Dried legumes	.78	.90	.97	3.4	8.5	4.0
Vegetables	.83	.90	.95	3.6	8.5	3.9
Fruits	.85	.90	.90	3.7	8.5	3.7
Total food of average mixed diet	.92	.95	.98	4.0	9.0	4.0

The values given in Table 11 show that the calories of fuel value of food calculated by the average figures of 4-9-4 are too low for animal foods and too high for vegetable foods, as pointed out by Maynard (46).

According to Fraps, Carlyle and Fudge (33), the metabolizable energy of foods for chickens on a maintenance basis can be calculated with an excellent degree of accuracy from the digestible constitutents by means of the values of 4.4 calories per gram of digested protein, 4.2 calories per gram of digested nitrogen-free extract and of digested crude fiber, and 9.47 calories per gram of digested ether extract. These values for the digestible constitutents are nearly the same as those used for human foods by Sherman. Considering the fact that heat of combustion found was slightly lower than the calculated value for the chickens in case of corn meal, flour, kafir, rice bran, rice polish and starch (33), the value of 4.1 calories per gram for digested nitrogen-free extract and crude fiber, as used by Sherman and others, appears equally as desirable as the value of 4.2 calories used for chickens.

Table 12 contains the average coefficients of digestibility of groups of human foods and the factors for calculating the metabolizable energy in calories per gram from the chemical composition, prepared with use of the values 4.35 calories per gram of digestible protein, 9.45 calories per gram of digestible fat and 4.1 calories per gram of digestible "carbohydrates." The metabolizable energy values of human foods are usually expressed in calories per pound; the factors for calculating directly to calories per pound from the percentage composition are also given in Table 12. Because no correction was made for non-proteid constitutents, the metabolizable energy factor for protein is too high for fruits and vegetables.

Table 13 contains the average composition of the edible portion of a number of human foods, from the compilation of Chatfield and Adams (12), together with the fuel value per pound as calculated by them, and the metabolizable energy as calculated from the factors given in Table 12. The productive energy is also given, which will be discussed on a subsequent page.

The fuel value was calculated (12) by use of 4 calories per gram for protein and carbohydrates and 9 calories per gram of ether extract, as found by analysis. These are assumed to be the values for a mixed animal and vegetable ration, and they make no allowance for differences in digestibility between the different classes of foods. The metabolizable energy is secured by the use of the values in Table 12, and allows for differences in digestibility of the constituents of the various classes of foods listed.

In the case of animal foods, the fuel value is lower than the metabolizable energy, for example, 990 and 1010 respectively for roast chuck beef; 445 and 456 for fish. With nuts, the fuel values are too high; 2,900 calories for almonds, compared with 2,604 calories for metabolizable energy; 2,720 for roasted peanuts, compared with 2,440 calories for metabolizable energy. The fuel values are too high for fruits, such as 290 calories per pound for apples compared with 279 calories metabolizable energy, and 230 calories for oranges compared with 216 calories of metabolizable energy. For beans the fuel value is 1,585 calories compared with 1,453 calories for metabolizable energy. For oat meal, the fuel value is 1,795 calories per pound and 1,663 for metabolizable energy. For fresh cabbage, the fuel value is 130 calories, while it is 104 calories

Table 12. Factors for calculating metabolizable energy in groups of human foods.

	Average digestibility, percent			Metabolizable energy, calories per gram			Metabolizable energy, calories per pound		
	Protein	Ether extract	Carbo-hydrates	Protein	Ether extract	Carbo-hydrates	Protein	Ether extract	Carbo-hydrates
Meat—bacon, beef, chicken, duck, ham, mutton, pork and veal	97	95	....	4.2	9.0	....	19.2	40.8	....
Eggs	94	95	....	4.1	9.0	....	18.5	40.8	....
Fish	95	92	....	4.1	8.7	....	18.8	39.5	....
Cheese	95	93	97	4.1	8.8	4.0	18.8	39.9	18.1
Milk, whole	92	97	89	4.0	9.2	3.7	18.2	41.6	16.6
Fats and oils	....	96	....	....	9.1	....	....	41.2	....
Cereals, barley, corn, farina, grape nuts, hominy, macaroni, oat meal, rice, wheat, buckwheat, rye flour	75	73	96	3.3	6.9	3.9	14.8	31.3	17.9
Bread, white, crackers, flour	87	75	98	3.8	7.1	4.0	17.2	32.2	18.3
Bread, graham, graham flour	81	65	93	3.5	6.1	3.8	16.0	27.9	17.3
Bread, rye	69	90	93	3.0	8.5	3.8	13.6	38.6	17.3
Sugar, granulated or powdered	....	....	100	....	....	4.0	....	....	17.9
Sweet potatoes (rats)	34	67	97	1.5	6.3	4.0	6.7	28.7	18.1
Potatoes, white	75	80	98	3.3	7.6	4.0	14.8	34.3	18.3
Wheat gray shorts (rats)	74	68	80	3.1	6.4	3.3	14.1	29.1	15.0
Wheat bran	44	70	57	1.9	6.6	2.3	8.7	30.1	10.6
Grain sorghums, feterita, kafir, milo	47	(75)	97	2.0	....	4.0	9.3	32.2	18.1
Legumes dried, beans and peas	78	62	93	3.4	5.9	3.8	15.4	26.6	17.3
Vegetables, mustard greens, spinach, Swiss chard, turnip greens	69	66	70	3.0	6.2	2.9	13.6	28.3	13.0
Vegetables, broccoli, cabbage, celery, collards, lettuce, snap beans	63	52	83	2.7	4.9	3.4	12.4	22.3	15.4
Vegetables, tomato, okra	39	49	79	1.7	4.6	3.2	7.7	21.0	14.7
Beet roots, carrots, egg plant, pumpkin, turnip roots	45	88	93	2.0	8.3	3.8	8.9	37.8	17.3
Fruits, apples, bananas, date, figs, grapes, olives, pears, persimmon, prune	70	81	94	3.1	7.7	3.9	13.9	34.7	17.5
Nuts, almonds, Brazil nut, chestnut, cocoanut, peanut, pecan, walnut	77	85	95	3.4	8.0	3.9	15.2	36.5	17.7
Mixed animal and vegetable diet	92	98	98	4.0	9.0	4.0	18.2	40.8	18.2
Yeast	80	0	96	3.5	0	3.9	19.3	0	17.9

Table 13. Composition, fuel value, metabolizable energy and productive energy of the edible part of human foods.

	Protein, percent	Ether extract, percent	Crude fiber, percent	Nitrogen-free extract, percent	Water, percent	Ash, percent	Fuel value, calories per pound	Metabolizable energy, calories per pound	Productive energy, calories per pound
Almonds, dried, unbleached	18.6	54.1	2.7	16.9	4.7	3.0	2900	2604	1825
Apples, fresh	.3	.4	1.0	13.9	84.1	.29	290	279	154
Apricots, fresh	1.0	.1	.6	12.3	85.4	.59	255	244	136
Bacon, medium fat, raw	9.1	65.0	....	(1.1)	20.0	4.3	2840	2827	2012
Bananas	1.2	.2	.6	22.4	74.8	.84	445	426	243
Barley, pearled, light	8.2	1.0	.5	78.3	11.1	.9	1620	1563	1132
Beans, snap, green	1.0	.1	.6	2.7	94.3	1.3	80	65	33
Beans, common, dried	22.0	1.5	3.9	58.2	10.5	3.9	1585	1453	1000
Beans, lima, dried	20.7	1.3	3.8	57.8	12.6	4.3	1545	1419	978
Beef side, wholesale, including kidney fat, thin	18.8	14.0	....	0	66.0	.97	910	932	656
Beef, wholesale, chuck, medium	18.6	16.0	....	0	65.0	.88	990	1010	711
Beef, wholesale cut, round medium	19.3	13.0	....	0	67.0	.95	880	901	633
Beets, fresh, peeled root	1.6	.1	.9	8.7	87.6	1.11	205	184	81
Brazil nuts	14.4	65.9	2.1	8.9	5.3	3.4	3150	2819	1987
Bread, graham, made with water	9.0	3.0	1.0	48.0	37.0	2.0	1175	1080	693
Bread, white, commercial	8.5	2.0	1.3	74.0	35.9	.3	1185	1168	775
Broccoli, fresh, flower stalks	3.3	.2	1.3	4.2	83.9	1.1	170	130	63
Butter	.6	81.0	0	.4	15.5	2.5	3325	3337	1912
Cabbage, fresh	1.4	.2	1.0	4.3	92.4	.75	130	104	51
Carrots, fresh	1.2	.3	1.1	8.2	88.2	1.02	205	152	74
Chickens, roosters	20.2	12.6	0	0	66.0	1.0	880	902	633
Cheese, Cheddar, American	23.9	32.3	0	1.7	39.0	3.1	1785	1769	1169
Coconut, fresh, meat	3.4	34.7	3.2	11.8	46.9	1.0	1730	1514	1096
Collards, leaves	3.9	.6	1.2	6.0	83.6	1.70	225	173	91
Corn, fresh, sweet	3.7	1.2	.8	19.7	73.9	.66	490	459	323
Corn meal, bolted	7.5	1.1	.8	78.0	12.0	.6	1610	1556	1170
Corn meal, whole grain	9.1	3.7	2.0	71.9	12.0	1.3	1665	1573	1161
Cowpeas, dry	22.9	1.4	4.2	57.4	10.6	3.5	1590	1445	997
Crackers, soda, plain	9.5	10.3	.2	72.5	4.5	.4	1885	1826	1214
Eggplant, fruit	1.1	.2	.9	4.6	92.7	.54	130	113	66
Eggs	12.8	11.5	0	.7	74.0	1.0	715	706	506
Fish, medium composition	19.0	2.5	0	0	77.2	1.3	445	456	316
Grapefruit	.5	.2	.3	9.8	88.8	.12	200	209	109
Grapes	.8	.4	.5	16.2	81.6	.46	335	317	181
Hominy	8.5	.8	.4	78.5	11.4	.4	1620	1563	....
Lamb, leg, intermediate	18.0	17.5	0	0	63.7	.9	1040	1060	747
Lamb, shoulder, intermediate	15.6	25.3	0	0	58.3	.8	1320	1332	942
Lard	....	100	....	....	....	....	4080	4120	2360

Table 13. Composition, fuel value, metabolizable energy and productive energy of the edible part of human foods.—Continued

	Protein, percent	Ether extract, percent	Crude fiber, percent	Nitrogen-free extract, percent	Water, percent	Ash, percent	Fuel value, calories per pound	Metabolizable energy, calories per pound	Productive energy, calories per pound
Lettuce, fresh	1.2	.2	.6	2.3	44.8	.91	85	64	32
Macaroni, dry, uncooked	13.0	1.4	.4	73.5	11.0	.7	1635	1559	1054
Margarine	0.6	81.0	0	.4	15.5	2.5	3325	3337	1912
Milk, cow, fresh, whole	3.5	3.9	0	4.9	87.0	.7	310	310	185
Mustard greens	2.3	.3	.8	3.2	92.2	1.21	125	92	47
Oatmeal, dry, uncooked	14.2	7.4	1.2	67.0	8.3	1.9	1795	1663	1189
Oil, salad or cooking	....	100	....	....	....	....	4080	4120	2360
Orange	.9	.2	.6	10.6	87.2	.47	230	216	119
Peaches, fresh	.5	.1	.6	11.4	86.9	.47	230	221	123
Peanuts, roasted	26.9	44.2	2.4	21.2	2.6	2.7	2720	2440	1710
Peanut butter	26.1	47.8	2.0	19.0	1.7	3.4	2805	2513	1767
Pears	.7	.4	1.4	15.8	82.7	.39	315	301	162
Peas, dry	23.8	1.4	5.4	54.8	11.6	3.0	1580	....	....
Peas, green	6.7	.4	2.2	15.5	24.3	.92	460	418	273
Peas, split (without seed coat)	24.5	1.0	1.2	60.5	12.6	2.8	1605	1471	1042
Pecans	9.4	73.0	2.2	10.8	3.0	1.6	3385	3037	2143
Pineapple	.4	.2	.4	13.3	85.3	.42	265	252	144
Pork, ham, fresh, medium	15.2	31.0	0	0	53.0	.8	1540	1557	1103
Pork, ham, smoked, medium	16.9	35.0	0	.3	42.0	5.4	1740	1753	1242
Pork, spare ribs, medium	14.6	32.0	0	0	53.0	.8	1570	1586	1123
Potatoes, Irish	2.0	.1	.4	18.7	77.8	.99	385	383	244
Prunes, dried	2.3	.6	1.6	69.4	24.0	2.1	1355	1295	745
Pumpkin, fresh	1.2	.2	1.3	6.0	90.5	.82	160	145	83
Rice, white, raw	7.5	1.7	.6	77.1	12.0	1.1	1615	1543	1124
Salmon, canned	20.1	9.6	0	0	67.4	2.4	765	767	536
Spinach, fresh	2.3	.3	.6	2.6	92.7	1.53	110	81	41
Squash, summer	.6	.1	.5	3.4	95.0	.44	85	64	32
Sugar, granulated	.5	....	....	99.5	....	....	1805	....	....
Sweet potatoes, fresh	1.8	.7	1.0	26.9	68.5	1.07	565	537	300
Tomatoes, fresh	1.0	.3	.6	3.4	94.1	5.7	105	73	36
Turnips, roots, fresh	1.1	.2	1.1	6.0	90.9	.73	155	140	83
Turnip tops, fresh	2.9	.4	1.2	4.2	89.5	1.76	165	121	60
Walnuts, English	15.0	64.4	2.1	13.5	3.3	1.7	3185	2855	2013
Wheat flour, graham, entire wheat	13.0	2.0	1.8	70.6	11.0	1.6	1630	1516	970
Wheat flour, straight	11.2	1.1	.4	74.8	12.0	.5	1615	1614	1061
Wheat flour, patent	10.8	.9	.3	75.6	12.0	.4	1545	1604	1061
Wheat gray shorts*	18.0	4.5	5.6	57.8	10.0	4.1	....	1336	848
Wheat bran, packaged	15.9	4.2	8.4	57.8	7.4	6.3	1660	965	472
Wheat, shredded	10.4	1.4	2.1	76.6	11.11	1.5	1675	1606	1063
Yeast, dried	46.1	1.6	.8	36.6	7.0	7.9	1580	1459	577

*Texas Average, Bul. 461

for the metabolizable energy. Some values are nearly the same, such as 385 and 383 for potatoes, 1,185 and 1,168 for white bread.

The use of method of calculation which produces the fuel value tends to cause the differences in the energy values of different kinds of feeds to be less than they really are, while the use of the metabolizable energy tends to bring out the differences which really exist. The factors for metabolizable energy need to be made more accurate for vegetable foods, fruits and nuts especially, for which additional digestion experiments are needed and by more exact evaluation of the effect of the crude fiber and the non-proteids upon the energy values.

Productive Energy

Productive energy is measured by the energy stored up as fat and protein by a growing or fattening animal from that portion of the ration which exceeds the quantity used for all maintenance purposes. The productive energy of a mixed feed as measured by means of growing chickens was 67.9 percent of the calculated metabolizable energy fed in excess of maintenance requirements (31). This means that on an average 67.9 percent of the metabolizable energy fed in excess of maintenance was stored up in protein and fat. The productive energy of corn meal, as measured by experiments with chickens, was 72 percent of the metabolizable energy, or 300 calories per gram of effective digestible nutrients (34). This means that the cost of utilization, including the work of digestion, the changes in energy consequent to the transformation of the nutrients to body protein and fat, and other changes consequent to the ingestion of the food, was 28 percent of the metabolizable energy of the corn meal fed, or 32 percent of the metabolizable energy of the mixed feed tested. Similar results were secured in experiments with rats (27).

While growing chickens may possibly utilize a greater percentage of the metabolizable energy for purposes of maintenance than for storage in protein and fat, the work indicates that the utilization of the energy for maintenance is in proportion to the productive energy (25).

Cost of utilization of a feed is the difference between the calories of metabolizable energy and the calories of productive energy of the food eaten. In case of productive energy, it consists of the energy consumed in digesting and utilizing the digested nutrients and in storing the protein and fat in the animals. This is a complicated process and involves a number of chemical changes of various kinds.

The cost of utilization of a given ration may depend upon the use made of the ration by the animal. When used for maintenance only, the cost of utilization may be less than when used for storage of protein and fat. Likewise the cost of utilization may be different when the food is used for energy of work than when used for production of fat. The production of milk may result in a different cost of utilization from the production of fat and flesh or of work.

The term net energy has been used to designate the energy value of a food for production of fat and flesh, for production of milk or of other animal products or for energy. The term productive energy is limited to use of the ration for production of flesh or fat on a growing animal, and therefore has a more definite meaning than the term net energy.

The productive energy values of 62 kinds of feed were measured in 192 tests on young growing chickens (25, 29, 30, 34, 35). Wide differences were found in the productive energy values of different kinds of feeds and foods, but these differences were found to be due chiefly to differences in digestibility. The ability of the chickens to utilize the digested material from the different feeds, on the average, was reasonably uniform. The productive energy values per digestible unit of many different feeds were usually within 10 percent of that of corn meal. Similar results were found in experiments with rats (23).

Very little data is available as to the productive energy of foods as measured by experiments on humans but this applies also to the fuel value or metabolizable energy, which was derived by Rubner from experiments with dogs.

Energy Production Coefficients for Human Foods

In the absence of experimental data for humans, the productive energy of human foods has been calculated from the data secured with experiments on chickens. Energy production coefficients for human foods have been calculated by the same methods as used for calculating the energy production coefficients for chicken feeds (28).

In previous publications on experimental work, the total energy, metabolizable energy, and productive energy, have been discussed in terms of calories per 100 grams. For many years, however, the energy values of human foods have been expressed in calories per pound of food (12, 48, 54) (metabolizable energy). In order to secure uniformity, the productive energy of human foods will here be expressed in calories per pound of food.

The productive energy of the feed or ration as measured by the experimental work has been reported in several different ways in previous publications, namely, in calories per 100 grams of the feed, in calories per 100 grams of the effective organic constituents, in calories per 100 grams of the effective digestible nutrients, and in percentage of the metabolizable energy (23, 28).

If the composition of the food is known or assumed, the effective digestible nutrients can be calculated from the results of digestion experiments on it, or from average digestion coefficients as previously given. Using the most probable value ascertained by experiment for productive energy of the effective digestible nutrients (35), the productive energy can be calculated in calories per 100 grams. The calories per 100 grams can then be converted to calories per pound by multiplying by 4.54.

This series of calculation can be made much shorter by using the energy production coefficients which combine the calculations named above and can be applied directly to the composition of the food, as has been done for the metabolizable energy in Table 13, and on preceding pages. The productive energy coefficient for protein of a particular feed gives the calculated calories of productive energy which will be furnished by one pound of protein in that feed. Similar coefficients are given for ether extract or fat and nitrogen-fee extract. The crude fiber is not assigned any value in calculating the productive energy, and the nitrogen-free extract is used for the purpose of the calculation, not the so-called carbohydrates.

Table 14 contains a calculation of the productive energy of average corn meal. The percentages in column 1 are multiplied by the corresponding productive energy coefficients in column 2 to secure the product in column 3. The total of the products in column 3 gives the productive energy of the average corn meal as calories per pound.

Table 14. Calculating the productive energy of corn meal, whole grain

Ingredient	Percentage of ingredient (Table 13) Col. 1	Energy production coefficient (Table 15) Col. 2	Product calories per pound Col. 3
Protein	9.1	10.2	92.8
Ether extract or fat	3.7	22.3	82.5
Crude fiber	2.0	0	0
Nitrogen-free extract	71.9	13.1	941.9
Total, productive energy, calories per pound of food			1,117.2

Energy production coefficients for groups of human foods are given in Table 15. The digestion coefficients are already given in Table 12 and are considered to be the most probable averages from the data in Tables 7 and 8. The productive energy values of the effective digestible nutrients, calories per gram as given in the Table 15, column 1, are the most probable values from the data in Bulletins 600, 625, 665, (24, 34, 35). The calories of productive energy (P.E.) per .01 pound for protein and nitrogen-free extract, column 2, are secured by multiplying the preceding column by 4.54. The calories of productive energy (P.E.) per .01 pound digestible fat, column 3, is the preceding column multiplied by 2.25; in the original work this ratio of fat to nitrogen-free extract was used. Columns 4 and 6 are secured from the respective coefficient of digestibility, Table 12, and the value in column 2. Column 5, for fat, is secured from the coefficient of digestibility of fat from Table 12 and the data in column 3.

Table 15 contains the energy production coefficients for groups of foods, and in the present state of knowledge these averages seem suitable and convenient for use. Energy production coefficients could also be calculated for the individual foods, average digestion coefficients of which are given in Tables 7 and 8. This will be desirable when more detailed information has been secured regarding the digestibility and energy values of some of these human foods.

Table 15. Energy production coefficients of groups of human foods

	P. E. of effective digestible nutrients cal. per gram	P. E. calories per .01 pound digestible nutrients		P. E. coefficients per pound		
		Protein	Fat	Protein	Fat	Nitrogen-free extract
Meat—Bacon, beef, chickens, ducks, ham, mutton, pork, veal	3.00	1.362	3.065	13.2	29.1	....
Eggs	3.00	1.362	3.065	12.8	29.1	11.3
Fish	3.00	1.362	3.065	12.9	28.2	....
Cheese	2.8	1.271	2.860	12.1	26.6	12.3
Milk, whole	2.8	1.271	2.860	11.7	27.7	21.3
Fats and oils	2.40	....	2.453	....	23.6	....
Cereals—barley, corn, hominy, oatmeal, rice	3.0	1.362	3.065	10.2	22.4	13.1
Cereals—Farina, grape nuts, macaroni, wheat, buckwheat flour, rye flour	2.8	1.271	2.860	9.5	20.9	12.2
Bread, white; crackers, flour	2.8	1.271	2.860	11.1	21.5	12.2
Bread, entire wheat; entire wheat flour, graham flour	2.7	1.226	2.759	9.9	17.9	11.4
Bread, rye	2.7	1.226	2.759	8.5	24.8	11.4
Wheat bran	2.7	1.226	2.759	5.4	19.3	7.0
Wheat gray shorts	2.8	1.271	2.860	9.4	20.0	10.2
Sugar (Sucrose)	2.8	1.271	....	....	....	12.7
Grain sorghums—feterita, kafir, milo	3.00	1.362	3.065	6.4	23.0	13.2
Legumes dried, peas and beans	3.00	1.362	3.065	10.6	19.0	12.7
Potatoes, white	2.80	1.271	2.860	9.5	10.2	12.0
Sweet potatoes	2.67	1.212	2.727	4.1	18.3	10.4
Vegetables—Mustard greens, spinach, Swiss chard, turnip greens	2.4*	1.09	2.453	7.5	16.2	7.6
Vegetables—Broccoli, cabbage, celery, collards, lettuce, snap beans	2.4*	1.09	2.453	6.8	13.0	9.1
Vegetables—Squash, tomato, okra, beet roots, carrots	2.4*	1.09	2.453	4.3	9.6	8.6
Vegetables—Eggplant, pumpkin, turnip roots	2.8*	1.271	2.860	5.7	25.2	11.8
Fruit—Apple, banana, date, fig, grapes, olive, pear, persimmon, prune	2.4*	1.09	2.453	7.6	19.9	10.3
Nuts—Almond, Brazil nut, chestnut, coconut, peanut, pecan, walnut	3.00	1.362	3.065	10.5	26.1	12.9
Yeast	1.8	.81	....	6.5	....	7.8

Productive Energy Values of Some Human Foods

The productive energy values of a number of human foods are given in Table 13, where they can be compared with the metabolizable energy, and the fuel energy. The average chemical composition and the fuel energy, calculated to calories per pound, were taken from the compilation previously discussed (12).

The productive energy is not always in proportion to the metabolizable energy. As can be seen from the factors in Table 13 (column 5), meat, eggs, certain cereals, and legumes have the highest proportionate values. Cheese, milk, certain cereals, white bread, white potatoes, sugar and a few vegetables have about one-fifteenth lower proportionate values. Next are entire wheat bread, rye bread, wheat bran, sweet potatoes, which have about one-tenth lower proportionate values. Fats and oils and most vegetables have about 20 percent proportionately lower value, while dried yeast is lowest. This discussion refers to the value of the productive energy in proportion to the metabolizable energy, and not to the relative productive energy value per pound of food.

It is obvious that a diet calculated on the basis of productive energy would be somewhat different from a diet calculated on the basis of the metabolizable energy.

The relative energy values of the human foods are probably given more accurately by the productive energy than by the metabolizable energy, and more accurately by the metabolizable energy, as here calculated, than by the fuel value as ordinarily calculated.

Productive Energy of Wheat Flour

The flour secured in the usual process of milling wheat is used as human food, while the by-products are usually used as animal food. Some authorities on food recommend the use of entire wheat flour or Graham flour as human food. In times of scarcity of food, as during and after World War I and World War II, governmental action sometimes requires the production of more flour than usual per bushel of wheat by reducing the quantity of by-products. Whole wheat flour may deteriorate more rapidly than patent flour, and may be more subject to insect damage. Average analyses (12) show that whole wheat flour is higher than patent flour in protein, fat, calcium, phosphorus, iron and the vitamins thiamin, riboflavin, and niacin. Whole wheat flour is also claimed (12, 54) to have a slightly higher value for food energy than patent flour, but this statement is not in accordance with the values given in this publication, Table 13.

The relative proportions of the different kinds of flour and feed produced from wheat depend upon the kind of wheat used, other characteristics of the wheat, and the variations in the process of milling made in the attempt to best meet the demands of the trade. According to correspondence with various millers doing business in Texas, ordinarily wheat produces about 70 percent flour and 30 percent wheat bran and wheat gray shorts. The by-products may range from 60 percent bran and 40 percent wheat gray shorts to 40 percent bran and 60 percent shorts.

A discussion of the terminology employed in describing flours has been presented by Snyder (55). Accompanying Snyder's contribution is a report of a committee representing the Millers National Federation in which a system of nomenclature and definitions for flour is suggested. The committee considers that there are no chemical or physical constants that can be used to establish flour standards and definitions, because of the great differences in the composition of wheats and corresponding differences in composition that occurs when flours are milled from different wheats by the various systems of milling.

Wheat of the same characteristics may produce flour of varying chemical composition from day to day in the same mill. The following definitions for the different grades were suggested:

Flour is finely ground bolted wheat meal.

Straight flour (or 100 percent flour) is all the bolted wheat meal recovered from the wheat after removal of feeds, usually after about 5 percent low grade flour is taken off.

Patent flour is the more refined portion of the wheat meal from which all or a portion of the clears have been removed. The patent flour may comprise from 60 to 95 percent of the total flour.

Clear flour is the less refined bolted portion of the wheat meal recovered in the manufacture of patent flour. Millers according to their processing or trade demands divide this into first and second clears.

First clear is the better portion of the clear when separated into two parts.

Second clear is the remaining portion of the clear when first clear is removed.

Patent flour usually contains lower percentages of protein and ash than the straight flour, and this, in turn, lower percentages than the clear flour.

The approximate energy value of Graham, or entire wheat flour, may be calculated from the percentages of straight flour, wheat bran and wheat gray shorts ordinarily produced from the wheat. For the purposes of this calculation, the wheat is assumed to produce 70 percent straight flour, 15 percent gray shorts and 15 percent wheat bran. The production energy calculations are made in Table 16.

The calculated metabolizable energy of the entire wheat flour, Table 16, is 1,475 calories per pound compared with 1,614 calories for the straight flour, and the productive energy is 941 calories compared with 1,061 for the straight flour. The values of the entire wheat flour calculated from the values of the straight flour, wheat bran and wheat shorts are close to those calculated from the energy production coefficients, Table 13.

Table 16. Calculation of energy value of entire wheat flour, calories per pound

Wheat products	Entire flour percent	Metabolizable energy calories	Metabolizable energy constituents calories	Productive energy calories	Productive energy constituents calories
Flour, straight........	70	1614	1130	1061	743
Wheat bran..........	15	965	145	472	71
Wheat gray shorts......	15	1336	200	848	127
Total, entire wheat flour...........	....	....	1475	....	941

The metabolizable energy calculated by means of the coefficient is 1,516 compared with 1,475 for Graham flour and the productive energy is 970 compared with 941 (Table 16) for Graham flour. The energy value per pound is appreciably lower in the entire wheat flour than in the patent or straight flour.

Productive Energy of Fats and Oils

In the comparison of the productive energy values of various feeds, cottonseed oil was substituted for corn meal. In the average of 6 experiments with young growing chickens, 57 percent of the metabolizable energy of cottonseed oil in excess of maintenance was stored, compared with 72 percent for corn meal (35). With the effective digestible nutrients of corn as 100 percent, cottonseed oil averaged 79 percent with a standard error of about 6.7 percent. In this work, instead of oil having 2.25 times the energy value of nitrogen-free extract, its energy value was about 1.8 times such value. The heat of utilization of oil was 43 percent of the metabolizable energy, compared with 28 percent for corn (35). The same energy values were found in six experiments with rats, namely 57 percent of the metabolizable energy was stored from oil compared with 72 percent from corn meal, and the effective digestible nutrients had 79 percent of the productive energy value of the effective digestible nutrients of corn meal.

According to Forbes et al. (17) diets containing 2, 5, 10, and 30 percent fat compounded and fed to growing rats so as to supply each rat the same quantities of gross energy, protein and vitamins, produced gains in live weight, digestibility of nitrogen and the retention of nitrogen in the order of the increasing fat content of the diets; the superiority of the 5 percent over the 2 percent fat diet with respect to the utilization of both protein and energy being much greater than the superiority of the 30 percent compared with the 5 percent diet. Examination of the data of the single experiment shows that the average gains in weight of the 5, 10 and 30 percent fat diet of 231, 235, and 239 grams are probably within the limit of error, and likewise the energy retained of 440, 456, and 460 calories are probably within the limit of error. Repetitions of this experiment are necessary to ascertain if there are really any differences in the energy value of the fat fed at these three levels.

From the results of a similar experiment with mature rats, in which voluntary activity during the respiration tests was excluded by subjecting the rats to a bright light, Forbes et al. (18) concluded that the heat production and the heat increments at maintenance and at supermaintenance diminished in the order of the increasing fat contents of the diets and that the heat increments of the dietary supplements containing 2, 5, 10 and 30 percent of fat respectively were equivalent to 36, 31, 29 and 20 percent respectively of their gross energy. Examination of the data shows that the differences in the heat production of the rats on 2, 5, and 10 percent fat diets may have been within the limit of error of the work. Calculation of the productive energy of the diets containing 2, 5, 10 and 30 percent fat gave 60, 65, 68 and 77 percent of the metabolizable energy. The productive energy of the first two diets was lower than usual, so that the appreciably high results for lard is in part due to the low productive energy of the basal diet. As Forbes et al. reported only one experiment, additional experiments seem to be needed to confirm the conclusions drawn.

Forbes et al. state (18) that the results represent growing animals during voluntary activity and mature animals at rest on diets comparatively low in fat content, by virtue of which they are not in conflict with numerous published findings that work is performed more efficiently at the expense of carbohydrates than of fat.

The productive energy value of lard has been reported by Forbes et al. (23) to be 6.59, 6.00, 6.28, 6.12 and (16) 7.57 calories per gram compared with the average of 5.10 for cottonseed oil with rats and 4.67 for chickens, by Fraps (23). The causes of these differences need to be ascertained—whether lard has a higher productive energy than cottonseed oil, or to what these differences are due.

According to Wald and Jackson (59) rats on a normal diet ran an average of 2,000 revolutions on the running wheel daily, but when deprived of food or water, their activity increased to 10,000 revolutions of the wheel daily. Increased activity occurred when the rats were deprived of thiamin or riboflavin, but not when they were deprived of vitamin A or of certain minerals. Deficiency in food nutrients may result in increases of activity. The additional running would increase the maintenance requirements of the rats, or decrease the apparent productive energy of the food, if allowance is not made for the increased activity.

It should be pointed out that in Table 15, the productive energy coefficients for all foods except fats and oils were calculated with the use of the factor 2.25 times carbohydrates for fat and oils. This factor was used in calculating the effective digestible nutrients in all work, and was not changed in calculating the productive energy coefficients for the various foods, which were derived from experiments on the entire food.

According to Borsook and Winegarden (7, 9), if the conversion of fat to glucose occurs it involves an energy loss of about 21 percent, and the difference between the efficiency of fat and glucose utilization for work is 11 percent. Keys (43) states that fat is about 16 percent less efficient than carbohydrates for production of muscular work.

Fat may be more of a heating food than either carbohydrates or protein.

Substitution of cottonseed oil for part of the corn meal in a standard ration produced chicks with a much higher fat content and a lower live weight than those grown on the standard ration alone (21). The fat reduced the growth but increased the fatness of the chickens, and in this respect had a specific action. Sustitution of casein or other protein feed for corn meal produced chickens with a lower fat content than those produced by the corn meal ration. While substitution of fat for corn meal increased the fat content of rats slightly (27) it did not have nearly as much effect upon rats as on chickens, and had little effect on the gain in weight.

Energy Cost of Utilization of Food Nutrients

The organic nutrients ingested by animals undergo a long and complex series of chemical changes before they are entirely utilized and the final products are ejected. Some of these changes contribute to the metabolic process and are necessary for life but others result in the production of heat which, while useful under some conditions, ordinarily has no value. These latter changes are included in the energy cost of utilization.

Approximately 70 percent of the metabolizable energy of food fed in excess of maintenance may be stored as fat and protein in growing chickens and 30 percent may be liberated as heat as the cost of such utilization.

The cost of utilization may include (47) the energy of chewing and transporting the food through the intestines, the energy consumed in the production of digestive enzymes, heat of bacterial action, especially in the digestive tract of ruminants, chemical changes of the material during digestion, energy of intermediate metabolism, stimulation of metabolism and chemical changes consequent on the storage of protein and fat.

The proteids, during digestion, may be split into about 21 amino acids (56), which are absorbed and partly converted to body proteids. Young growing chickens may store 57 percent of the digested protein or 57 percent of the protein consumed in excess of maintenance (31). Amino acids appear in the blood, are absorbed by the tissues, transformed into other amino acids (52) by transanimation or transmethylation, or deaminized, so as to produce urea and glucose. The oxidation of ammonia to urea releases about 4 calories per gram of nitrogen; the energy cost of excretion of urea and other end products by the kidneys involves a loss of perhaps 1 to 2 calories per gram of nitrogen (9). Transformations of some amino acids are exothemic, others endothermic and involve loss of energy (9).

Years ago, Rubner (4, 5) found that if a dog deprived of food required 100 calories per day for maintenance, the requirement would be 140 calories if fed meat, 115 calories if fed fat and 106 calories if fed cane sugar. The extra calories are considered as due to the specific dynamic action of the food (44, 45). If a maintenance ration is fed at intervals of two hours, the heat production does not rise appreciably above the basal metabolism level (9) and a small breakfast also exerts no specific dynamic action. The specific dynamic action does not represent the heat of utilization of the food, but the difference between the heat of utilization of the food and of the body nutrients which would have been used if the food were not given (9, 18).

Digestive processes cause the hydrolysis of fats into glycerol and fatty acids. The split products are readily absorbed and converted into fat in the passage through the intestinal walls (10). According to Frazer (36) unhydrolyzed or partly hydrolyzed fat may be absorbed. Fats undergo other changes. Stearic acid may be changed to palmitic acid, or the reverse may occur, unsaturated fatty acids may be saturated, or the reverse. A portion of the fats are desaturated and built into the phosphatide molecule. Portions are also stored. Fats may also be formed from sugars, which involves loss of energy (18).

Starches are converted by digestive enzymes first into maltose, then the maltose is hydrolyzed to glucose. Sugars such as sucrose, and milk sugar are hydrolyzed to the simpler sugars glucose, fructose and galactose. Part of the glucose in the blood stream may be stored in the liver as glycogen and part may be converted to fats. The carbon of bicarbonates may be incorporated to the extent of about 12 percent into the glycogen, so that the reaction is not simply condensation of glucose with elimination of water (52). Glucose undergoes intermediate changes, such as phosphorylation, on the path to storage or complete oxidation, which involve loss of energy.

Kertesz (42) reports that pectins are not digested by the saliva or secretions of the stomach or intestines but are rapidly decomposed when incubated with human feces, and probably not assimilated.

Experiments with isotopic elements have shown that the body constituents are involved in continuous chemical processes and that there exists a close interaction between the food materials and body components. Protein, ester and other linkages open and close continuously. The amino acids, fatty acids and other units temporarily liberated mix with others from diet or tissue sources and become indistinguishable in origin. While in the free state the organic units take part in a variety of reactions (52).

The cost of the utilization of digested nutrients by humans for the storage of protein and fat is probably not far from the cost of the utilization of digested nutrients by chickens for the storage of protein and fat. However, only a small percentage of the energy of the food is used by humans for production of protein and fat, even during periods of rapid growth. The value of the food energy for maintenance or work by humans may be in proportion to the productive energy, and the productive energy may be a better measure of the relative net energy value of the food than the metabolizable energy; further investigation is needed.

The percentage of metabolizable energy retained by humans in the form of protein and fat under normal conditions is quite small. According to Brody, page 566 (9), boys average 21.2 pounds in weight at the age of 1 year and 26.5 pounds at the age of two years, thus making a gain of 5.3 pounds in a year. If the gain is assumed to contain 2.2 calories a gram (23) or 1,000 calories a pound, the total gain would be 5,300 calories a year, equal to 14.5 calories a day. If the consumption of food is assumed to be 1,200 calories of metabolizable energy equal to 840 calories of productive energy a day, Table 17, the gain in weight would be 1.2 percent of the calories of metabolizable energy or 1.7 percent of the productive energy. Therefore, a very small proportion of the energy consumed is stored up as gain in a growing child. At the period of greatest gain, a boy 14 years old averages 103.1 pounds and at 15, 116.7 pounds, with a gain of 13.6 pounds a year equal to 37.3 calories per day. The daily allowance, Table 17, is 3,200 calories of metabolizable energy or 2,200 calories of productive energy. The energy in the gain in weight would be 1.2 percent of the calories of metabolizable energy or 1.7 percent of the calories of productive energy.

A fully grown person normally retains even smaller percentages of the energy of the food consumed. Almost all of the food is used for maintenance, or for the energy of work.

Young growing chickens may store an average of 57.9 percent of the productive energy of a corn meal ration, and young rats may store 32.4 percent, Table 11, Bulletin 632 (23).

Magnus-Levy, as cited by Sherman (54), estimated the minimum metabolizable energy of a fasting man of average size kept motionless to be 1,625 calories per day, and food sufficient for maintenance under the same condition would increase this by 175 calories. The heat of utilization of the food in excess of the heat of utilization of body tissue would thus be 175 divided by 1,800, or nearly 10 percent. Lusk, as stated by Sherman (54), estimated that an average-sized man with absolute rest in bed without food would require 1,680 calories, and under the same conditions with food would require 1,840 calories. The heat of utilization of the food in excess of that of the body tissue would then be 160 divided by 1,840, or 8.7 percent. These data do not measure the heat of utilization of the food ingested, but measure the difference between the heat of utilization of the food ingested and the heat of utilization of the body nutrients which would otherwise be oxidized.

Daily Allowances for Calories of Metabolizable Energy and of Productive Energy

The daily allowance of calories (presumably of metabolizable energy) are recommended by the Food and Nutrition Board of the National Research Council (15, 57) and these allowances are similar to those pre-

Table 17. Assumed daily allowances of metabolizable energy and productive energy (70 percent)

	Metabolizable energy, calories	Productive energy, calories
Men (70 kg)		
Sedentary	2500	1700
Moderately active	3000	2100
Very active	4500	3100
Women (56 kg)		
Sedentary	2100	1500
Moderately active	2500	1700
Very active	3000	2100
Pregnancy (latter half)	2500	1700
Lactation	3000	2100
Children up to 12 years		
Under 1 year (per kg)	100	70
1–3 years	1200	800
4–6 years	1600	1100
7–9 years	2000	1400
10–12 years	2500	1700
Girls 13–15 years	2800	1900
16–20 years	2400	1700
Boys 13–15 years	3200	2200
16–20 years	3800	2700

viously published. The productive energy, Table 17, was calculated on the assumption that 70 percent of the metabolizable energy of the mixed diet was productive energy. This is a little lower than the percentage of metabolizable energy of corn meal, and a little higher than the percentage of metabolizable energy of the feed mixtures used by the chickens. Human foods contain less crude fiber than those used for chickens. The figures, as rounded off, are given in Table 17.

Use of productive energy in place of metabolizable energy will change the relative energy values of most foods to a comparatively small extent. Whether or not it should replace the present system remains for the future to decide. The present system can be improved and made more accurate.

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SUMMARY

The average composition of a number of human foods analyzed are given.

Many vegetable foods on the dried basis contain 7 to 15 percent crude fiber, and others contain 20 to 42 percent protein.

Human digestion experiments are given on oat meal, collards, cabbage, and string beans.

The average digestibility of human foods, as compiled by the data in the literature, are given, with references.

The fuel values in calories of human foods, as given in the literature, are based on average values for the digestibility of a mixed diet of animal and vegetable origin, and are too low for many animal foods, too high for many vegetable foods, and do not show differences between some foods due to differences in digestibility.

Factors for calculating metabolizable energy are given, which take into consideration differences in digestibility of various groups of food. On account of the deficiency of adequate data, these factors do not correct for non-proteid nitrogen, and for crude fiber found in vertain vegetables.

The composition and fuel values of a number of human foods are given as compiled by Chatfield and Adams, with the metabolizable energy and the productive energy as calculated from the data presented in this bulletin.

As illustrative data, the fuel value is 990 calories per pound of roast chuck beef, compared with 1,010 calories of metabolizable energy; 2,900 calories fuel value for almonds, 2,604 calories metabolizable energy; 2,720 calories fuel value for roasted peanuts, 2,440 calories of metabolizable energy; 1,585 calories fuel value for beans, 1,453 calories of metabolizable energy; 130 calories fuel value for fresh cabbage, 104 calories metabolizable energy.

The productive energy is measured by the energy stored up as fat and protein by growing chickens from that portion of the ration which exceeds the quantity used for all maintenance purposes, and as given in previous publications for various foods.

Cost of utilization for productive energy is the difference between the calories of metabolizable energy and calories of productive energy in a unit of a food and is about 30 percent of the metabolizable energy of a ration by growing chickens.

Production coefficients are given for groups of foods, which can be used for calculating the productive energy values of human foods.

The computed productive energy values are given for a number of human foods.

The productive energy values are not always in proportion to the metabolizable energy values. Meat, eggs, certain cereals and legumes have the highest proportionate values; cheese, milk, certain cereals, white bread, white potatoes and sugar have slightly lower proportionate values. Next comes entire wheat bread, rye bread, wheat bran and sweet potatoes. Fats and oils have about 20 percent lower proportionate values.

The relative energy values of human foods are probably given more nearly accurately by the productive energy values than by the metabolizable energy values. The metabolizable energy and productive energy values of entire wheat flour, or bread from it, are lower than the corresponding values for white flour, whether calculated from the coefficients, or from the energy value of the bran, gray shorts and flour which can be produced from the entire wheat.

Daily allowances for productive energy in the human diet are calculated from the allowances recommended for metabolizable energy, on the assumption that the productive energy is 70 percent of the metabolizable energy.

Previous work has shown that fats and oils have a productive energy of 1.8 times that of carbohydrates, instead of 2.25 times that they are usually supposed to have. Fats and oils therefore, appear to be more heating foods than carbohydrates but this matter requires further study.

The storage of protein and fats by humans, the energy cost of utilization of human foods by humans, losses in energy consequent on the ingestion of human food, and transformation of nutrients in the body are briefly discussed.

REFERENCES

1. Armsby, H. P. 1917. The nutrition of farm animals. The Macmillan Company, New York City.
2. Association of Official Agricultural Chemists. 1940. Methods of Analysis.
3. Atwater, W. O. 1887. Century Magazine. July 1887.
4. Atwater, W. O. 1895. Methods and results of investigations of the chemistry and economy of foods. U. S. Department Agriculture, Office Exp. Sta. Bul. 21.
5. Atwater, W. O. and Bryant, A. P. 1899. Report Storrs (Conn.) Agr. Exp. Sta. 1899 73.
6. Atwater, W. O. and Bryant, A. P. 1899. The chemical composition of American food materials. U. S. Department Agriculture Office, Exp. Sta. Bul. 28 (revised).
7. Borsook, H. and Winegarden, H. M. 1930. The free energy of glucose and tripalmitin. Proc. Nat. Acad. Sci. 16:559.
8. Bridges, M. A. 1935. Food and Beverage analyses. Lea and Febiger, Philadelphia, Pa.
9. Brody, Samuel. 1945. Bioenergetics and growth. Reinbold Publishing Corporation, New York City.
10. Bloor, W. R. 1943. Biochemistry of the fatty acids and their compounds the lipids. Reinbold Publishing Corporation, New York.
11. Bureau of Human Nutrition and Home Economics U. S. Department of Agriculture in cooperation with National Research Council. 1945. Tables of food composition in terms of eleven nutrients. U. S. Department of Agriculture Miscellaneous Publication No. 572.
12. Chatfield, C., Adams, G. 1940. Proximate composition of American food materials. U. S. Department of Agriculture Circular 549.
13. Cowgill, G. R. 1945. Relative nutritive values of animal and vegetable fats. Physiol. Rev. 25:664-686.
14. Du Bois, E. F. 1927. Basal Metabolism in Health and Disease. Lea and Febiger, Philadelphia, Pa.
15. Food and Nutrition Board, National Research Council. 1943. Recommended dietary allowances. Reprint and Circular Series. National Research Council, Circuler 115.
16. Forbes, E. B. and Smith, R. W. 1944. Associative dynamic effects of protein, carbohydrates and fat. J. Nutrition 27:453-468.
17. Forbes, E. B., Swift, R. W., Eliott, R. F., and James, W. H. 1946. Relation of fat to economy of food utilization. I. by the growing albino rat. J. Nutrition 31:203-212.
18. Forbes, E. B., Swift, R. W., Elliott, R. F., and James, W. H. 1946. Relation of fat to economy of food utilization. II. by the mature albino rat. J. Nutrition 31:213-227.
19. Fraps, G. S. 1913. Principles of Agricultural Chemistry. Chemical Publishing Co., Easton, Pennsylvania.
20. Fraps, G. S. 1925. Energy production coefficients of American feeding stuffs for ruminants. Tex. Agr. Exp. Sta. Bul. 329.
21. Fraps, G. S. 1931. Digestibility by chickens of the constituents of the nitrogen-free extract of feeds. Tex. Agr. Exp. Sta. Bul. 437.
22. Fraps, G. S. 1943. Relation of the protein, fat and energy content of the ration to the composition of chickens. Poultry Sci. 22:421-424.
23. Fraps, G. S. 1943. Productive energy of certain feeds as measured by production of fat and flesh by growing rats. Texas Agr. Exp. Sta. Bul. 632.
24. Fraps, G. S. 1944. Digestibility of feeds and human foods by chickens. Tex. Agr. Exp. Sta. Bul. 663.
25. Fraps, G. S. 1944. Maintenance requirements of chickens and production energy of feeds as related to age. Texas Agr. Exp. Sta. Bul. 665.
26. Fraps, G. S. 1945. Utilization of metabolizable energy by growing chickens. Arch. Biochem. 8:21-27.

27. Fraps, G. S. 1945. Digestibility of human foods and animal feeds as measured by digestion experiments with rats. Tex. Agr. Exp. Sta. Bul. 675.

28. Fraps, G. S. 1946. Composition and productive energy of poultry feeds and rations. Tex. Exp. Sta. Bul. 678.

29. Fraps, G. S. and Carlyle, E. C. 1939. Utilization of energy of wheat products by chickens. J. Nutrition 18:385-398.

30. Fraps, G. S. and Carlyle, E. C. 1939. Energy values of corn bran, rice polish, rice bran and rye flour as measured by experiments on baby chicks. Proc. Amer. Soc. Ani. Nutr. 1939.

31. Fraps, G. S. and Carlyle, E. C. 1939. The utilization of the energy of feed by growing chickens. Texas Agr. Exp. Sta. Bul. 571.

32. Fraps, G. S. and Carlyle, E. C. 1940. Relation of gain in weight to gain in energy content of growing chickens. Jour. Agri. Res. 59:777-781.

33. Fraps, G. S., Carlyle, E. C., and Fudge, J. F. 1940. Metabolizable energy of some chicken feeds. Tex. Agr. Exp. Sta. Bul. 589.

34. Fraps, G. S. and Carlyle, E. C. 1941. Productive energy of corn meal, alfalfa leaf meal, dried buttermilk and casein as measured by production of fat and flesh in growing chickens. Texas Agr. Exp. Sta. Bul. 600.

35. Fraps, G. S. and Carlyle, E. C. 1942. Productive energy of some feeds and foods as measured by gains of energy of growing chickens. Texas Agr. Exp. Sta. Bul. 625.

36. Frazer, A. C. 1938. Fat absorption and metabolism. Analyst 63:308.

37. Grindley, H. S., Mojonnier, T., and Porter, H. C. 1907. Studies of the effect of different methods of cooking upon the thoroughness and ease of digestion of meat. U. S. Department Agriculture Office Exp. Sta. Bul. 193.

38. Hutchinson, R. and Mottram, V. H. 1933. Food and the principles of dietetics, seventh edition.

39. Jaffa, M. E. 1903. Further investigations among fruitarians. U. S. Department Agriculture Office Exp. Sta. Bul. 132.

40. Jones, J. D., Munsey, V. E. and Walker, L. E. 1942. Report of committee on protein factor. Jour. Assoc. Agr. Chem. 25:118-120.

41. Kellner, O. 1905. Die Ernahrung des landwirthschaftlicher nutztiere.

42. Kertesz, Z. I. 1940. Pectic enzymes. V. The fate of pectins in the animal body. J. Nutrition 20:289-296.

43. Keys, Ancel. 1945. Refinement of metabolizable calculations for nutritional purposes. J. Nutrition. 29:81-84.

44. Lusk, G. 1928. The Science of Nutrition. Philadelphia.

45. Lusk, G. 1931. The specific dynamic action. J. Nutrition 3:519-529.

46. Maynard, L. A. 1944. The Atwater system of calculating the caloric value of diets. J. Nutrition 28:443-452.

46a. McCance, R. A. and Windowsen, E. M. 1940. Chemical composition of Foods (British). Chemical Publishing Co.

47. Mitchell, H. H. and Hamilton, T. S. 1929. The Biochemistry of the Amino Acids. The Chemical Catalog Company, New York.

48. Morey, N. B. 1936. Analysis and comparison of different methods of calculating the energy values of diets. Nutrition Abstracts and Reviews 6:1-12.

49. Morrison, F. B. 1936. Feeds and Feeding. The Morrison Publishing Co., Ithaca, N. Y.

50. Oshima, K. 1905. Digest of Japanese investigations on the nutrition of man. U. S. Department Agriculture Office Exp. Sta. Bul. 159.

51. Phillips, M., Gross, M. J., and Browne, C. A. 1933. Determination of uronic acids and methoxyl in certain plants and plant materials. Jour. A.O.A.C. 16:289-292.

52. Schoenheimer, R. and Rittenberg, D. 1940. The study of the intermediary metabolism of animals with the aid of isotopes. Physiol. Rev. 20:218-249.

53. Sherman, H. C. 1911. Chemistry of Food and Nutrition. The Macmillan Company, New York.

54. Sherman, H. C. 1941. Chemistry of Food and Nutrition, Sixth Edition. The Macmillan Company.

54a. Sheets, O. A., McWhirter, L., Anderson, W. S., Geiger, M., Aschan, L., Cochran, H. L., Speirs, M., Reder, R., Edmond, J. B. Lease, E. J., Mitchell, J. H., Fraps, G. S., Whitacre, J., Yarnell, S. H., Ellett, W. B., Moore, R. C., and Zimmerly, H. H. 1944. The effect of fertilizer, soil composition and certain climatological conditions on the calcium and phosphorus content of turnip greens. Jour. Agr. Res. 68:145-189.

55. Snyder, H. 1923. The nomenclature of wheat flour. Millers National Federation, Chicago, Illinois.

56. Van Slyke, D. D. 1942. Physiology of the amino acids. Science 95:259-263.

57. Wilder, R. M. 1945. Misinterpretation and misuse of recommended dietary allowances. Science 101:285-288.

58. Wilhelmy, C. M. 1935. The specific dynamic action of food. Physiol. Rev. 15:202-220.

59. Wald, G. and Jackson, R. 1945. Emigration and food. Science News Letter for February 17, 1945. Nutritions Reviews February 1945.